Multimedia Communication over Wireless Networks

Avideh Zakhor
Video and Image Processing Lab
U.C. Berkeley
www-video.eecs.berkeley.edu

MM communications

- Multimedia:
  - Audio, video, text, graphics, 3D
- Communications:
  - Unicast: one to one; braodcast: one to many, multicast: many to many; anycast
  - Wired vs. wireless
  - Analog vs. digital
  - One way streaming, two way interactive, live
  - Broadband vs. narrowband

Why MM communications today?

- Stars are all aligned:
  - Fast, high bandwidth networks everywhere:
  - Fast, low power terminals cheap and available
  - Display technology

Multimedia communications

- MM requirements different from data:
  - delay sensitive: late packet as good as lost.
  - massively compressed
  - not sensitive to loss
  - graceful degradation to loss and delay
  - unlike data BER is not an indicative of performance; audio/visual quality is.
  - bits of unequal importance
- Solution lies somewhere in between Signal Processing (SP) and Networking.

Bag of tricks from SP and Networking and intersection

- Signal Processing and communications:
  - Source coding, channel coding, joint source channel coding, unequal error protection
  - Layered compression; multiple description coding;
  - Error resilient compression: reversible VLC, sync,
- Networking:
  - Protocol design: TFRC
  - QoS enabled networks: diffserv, MPLS
  - Architecture: edge architecture, overlay, distributed
- Intersection:
  - packetization issues

Prospective on Problems in MM Communication

- Unicast streaming MM over wired IP networks is mature and well understood
  - TFRC = TCP Friendly Rate Control
- Wireless streaming has more open issues:
  - Loss is not due to congestion, but due to packet loss at the physical layer
  - What is the equivalent of TFRC in wireless networks?
  - Can we exploit path diversity in wireless?
- Peer to peer streaming:
  - Decentralized way of disseminating video information
  - Application layer multicast; overlay networks;

Outline of the talk

- What is the equivalent of TFRC for wireless?
  - How to do rate control for wireless?
- How to exploit path diversity in wireless ad hoc networks?
  - Unicast
  - multicast

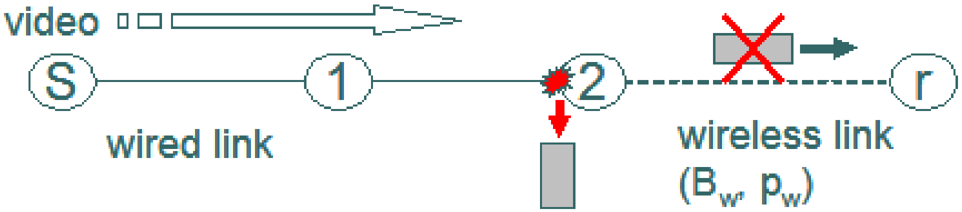
Motivation for Rate Control

- Rate control is important:
  - fully utilize wireless bandwidth
  - fair to TCP-based applications
- TFRC (TCP-friendly Rate Control) and TCP assume packet loss is caused by congestion wire-line Internet
- Wireless physical channel also causes packet loss:
  - In 1xRTT CDMA network, TFRC achieves 56% utilization on
- Open issues

	Wired	Wireless
DATA	TCP	-
VIDEO	TFRC	?

Goal: highest throughput, lowest end-to-end packet loss rate

- A simple scenario



  - B_w - available wireless bandwidth
  - p_w - packet loss rate due to channel error
  - p_c - packet loss rate due to congestion on node 2
  - $p=p_w+p_c(1-p_w)$ - end-to-end packet loss rate
- Maximum throughput: $B_w(1-p_w)$
- TFRC sending rate T:

$$T = \frac{k\ S}{rtt\sqrt{p}} \leq \frac{k\ S}{rtt\sqrt{p_w}} \equiv T_b$$

  - S - packet size
  - rtt - end-to-end round trip time
- Necessary and sufficient condition for underutilzation

$$T_b \leq B_w$$

Existing Work

- Differentiate between congestion and physical channel loss
  - Apply traditional wired-line rate control

- Changes needed to the infrastructure
  - Balakrishnan et.al. SIGCOMM 96
  - Ratnam and Matta International Journal of Communications 03
  - Choi et.al. IWMWCN 02
  - Ding and Jamalipour PIMRC 01
  - Cobb and Agrawal ISCC 95
  - Huang et.al. ACM WWMM 02
  - Chiasserini and Meo Globecom 01

- ECN or ELN based
  - Balakrishnan and Katz Globecom 98
  - Yang et.al. Globecom 02

- End-to-end statistics based
  - Biaz and Vaidya SASSET 99
  - Samaraweera Proceeding of communications 99
  - Lee et.al. SPIE 03
  - Sinha et.al. WCNC 99
  - Cen et.al. MMCN 02

Question

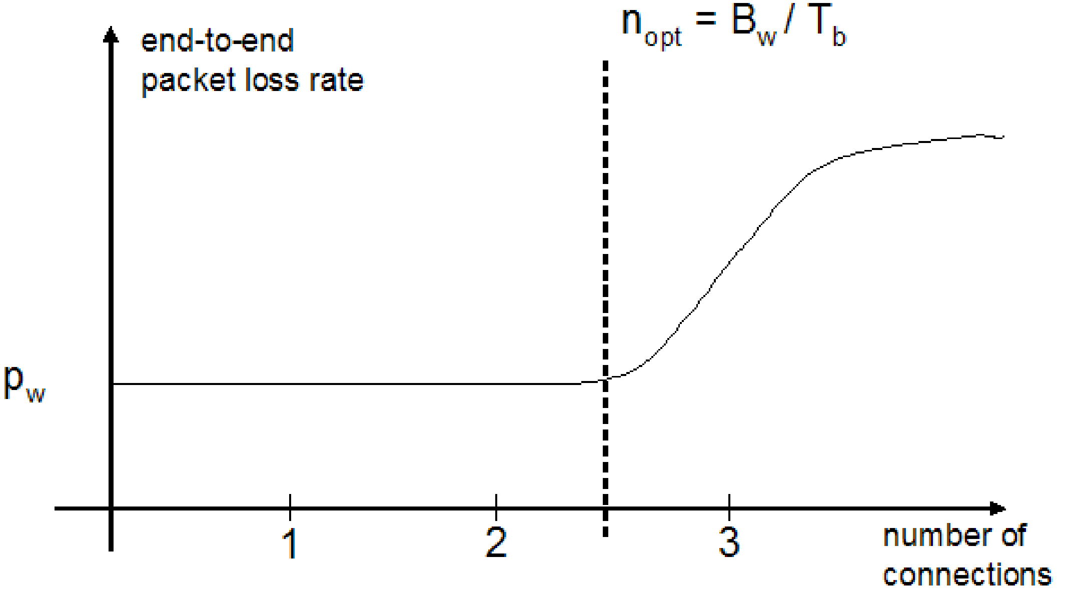
- Can we achieve best possible performance using an end-to-end solution?

- Best is defined as:
  - Maximize throughput
  - Minimize end-to-end packet loss rate

Proposal : open multiple TFRC connections

- Example case: $B_w=2.5T_b$, open n TFRC:
- n=1: throughput $T_b(1-p_w)$, $p=p_w$
- n=2: throughput $2T_b(1-p_w)$, $p=p_w$
- n=3: throughput $B_w(1-p_w)$, $p>p_w$

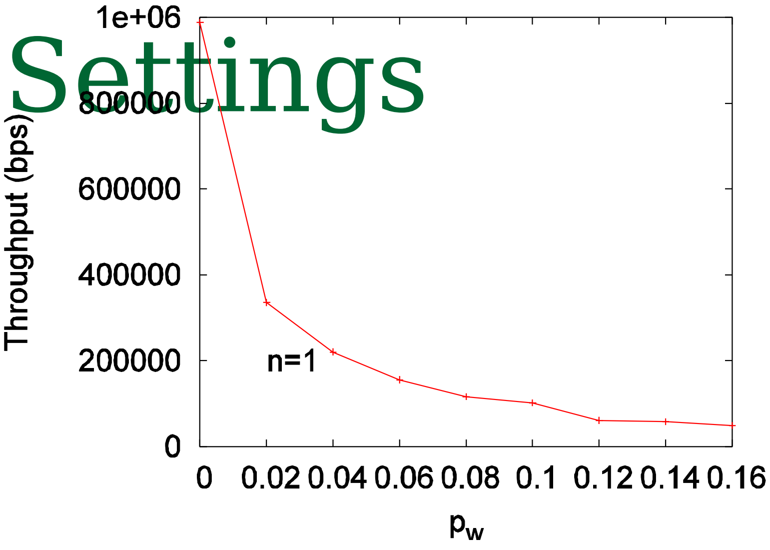
- $n=n_{opt}=2.5$: throughput $B_w(1-p_w)$, $p=p_w$

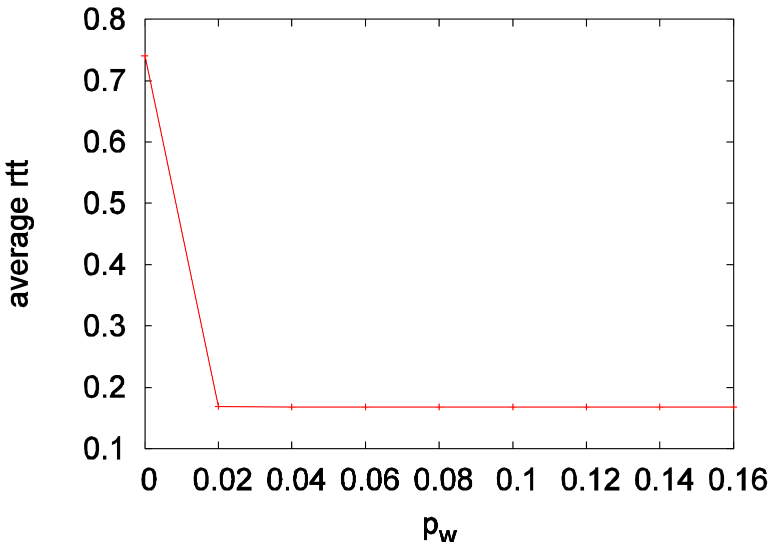
- 

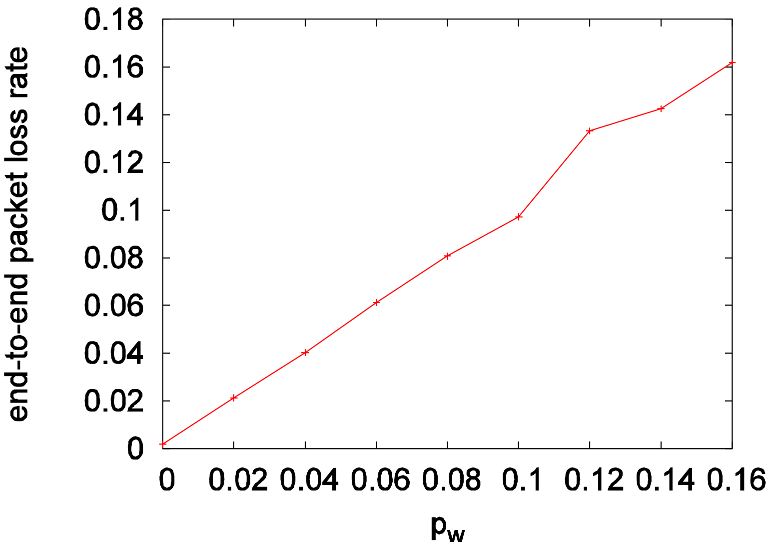
Optimal Number of Connections Exists for Given Settings

- B_w = 1Mbps
- Propagation delay: rtt_{min}=168 ms
- S=1000 bytes
- p_w varies from 0.0 - 0.16
- NS-2 simulation

- n=1



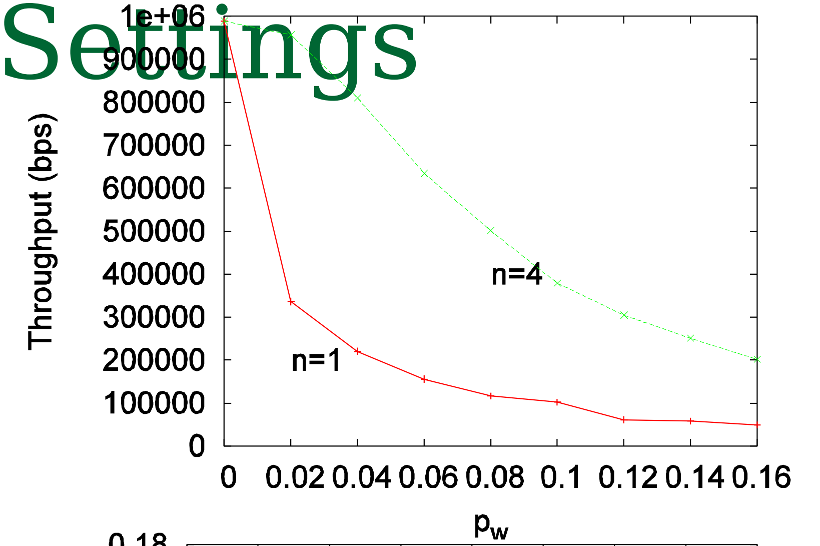


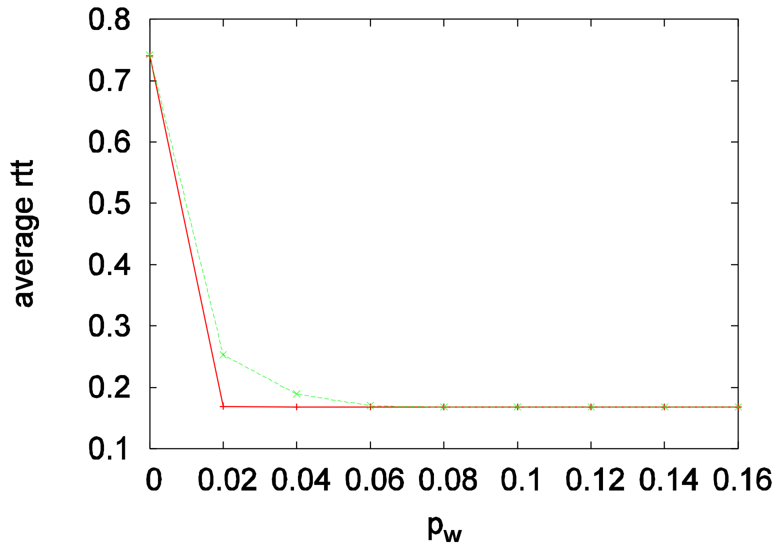


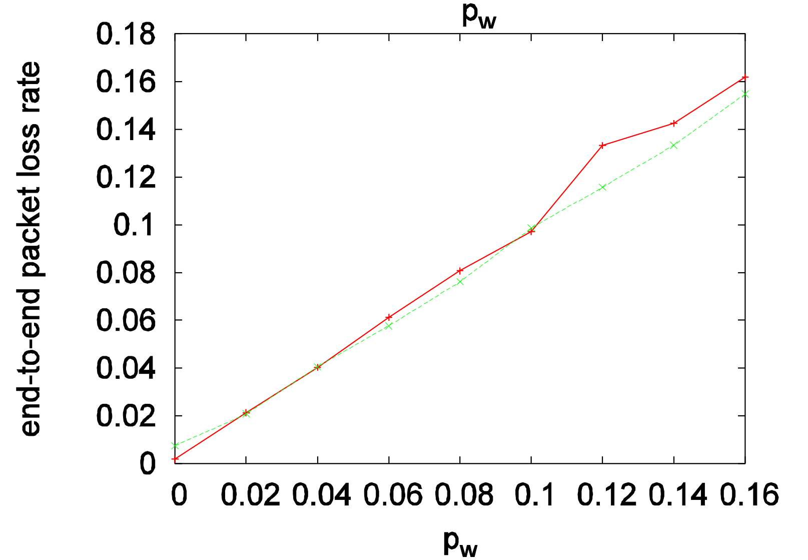
Optimal Number of Connections Exists for Given Settings

- B_w = 1Mbps
- Propagation delay: rtt_{min}=168 ms
- S=1000 bytes
- p_w varies from 0.0 - 0.16
- NS-2 simulation

- n=4



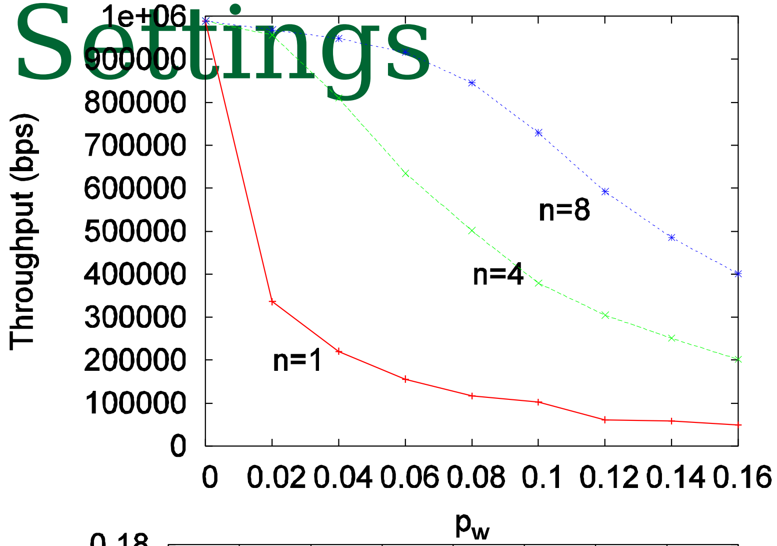


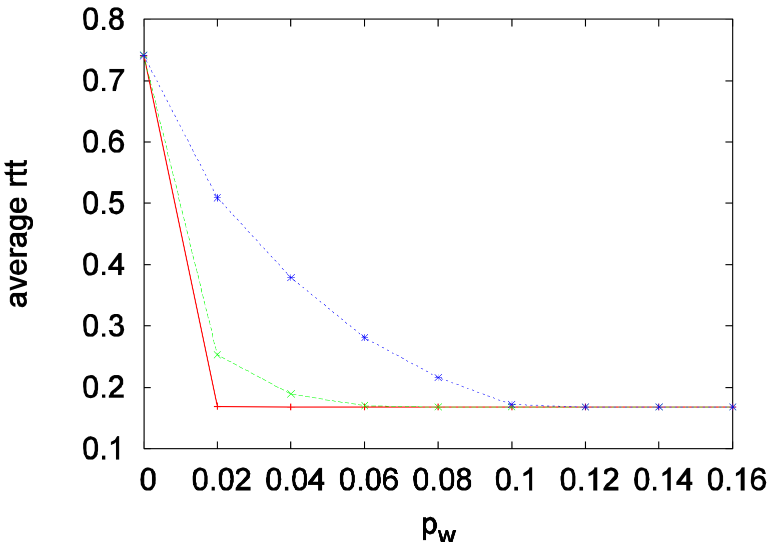


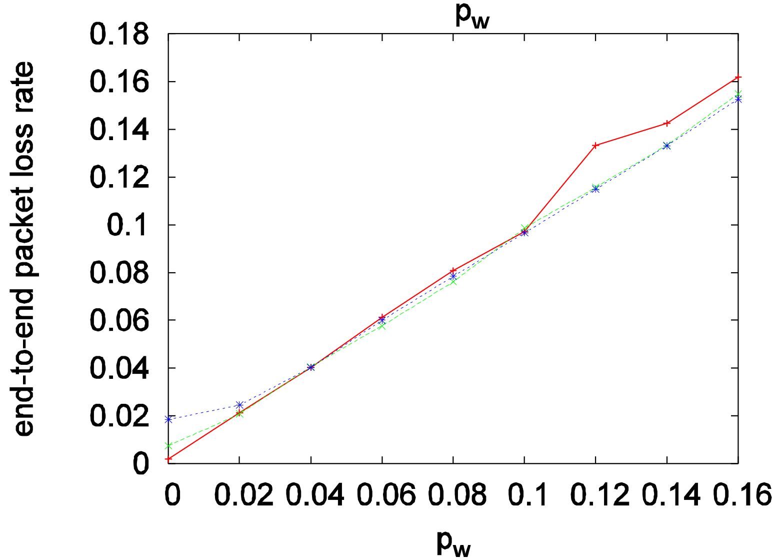
Optimal Number of Connections Exists for Given Settings

- B_w = 1Mbps
- Propagation delay: rtt_{min}=168 ms
- S=1000 bytes
- p_w varies from 0.0 - 0.16
- NS-2 simulation

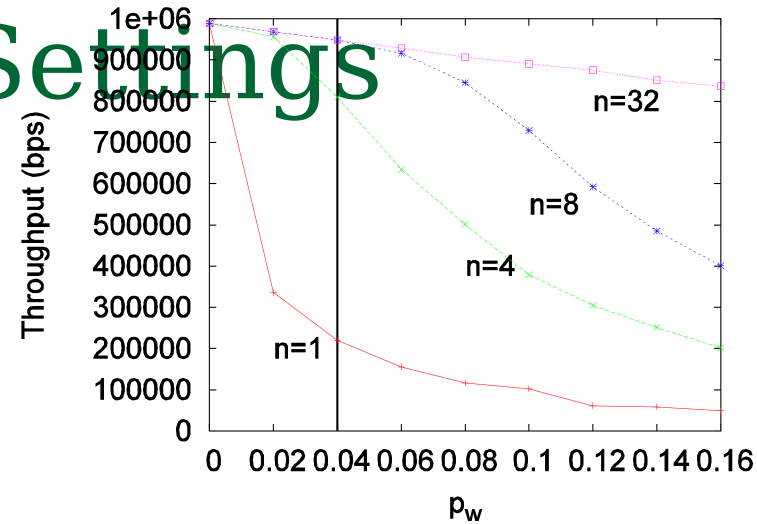
- n=8





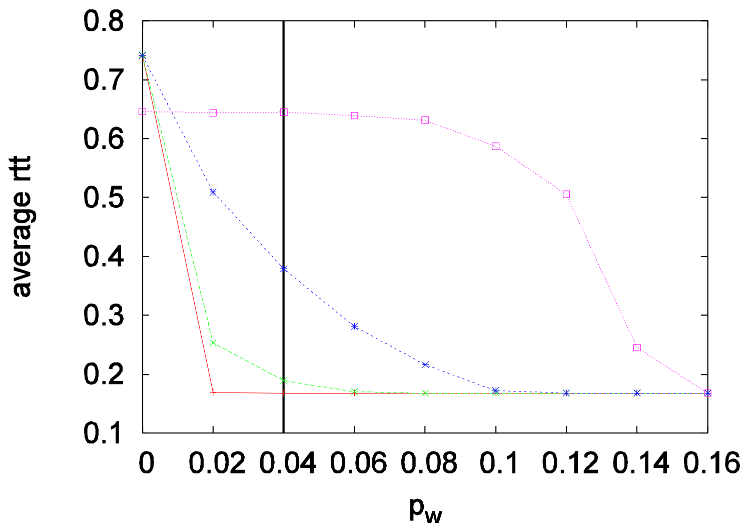


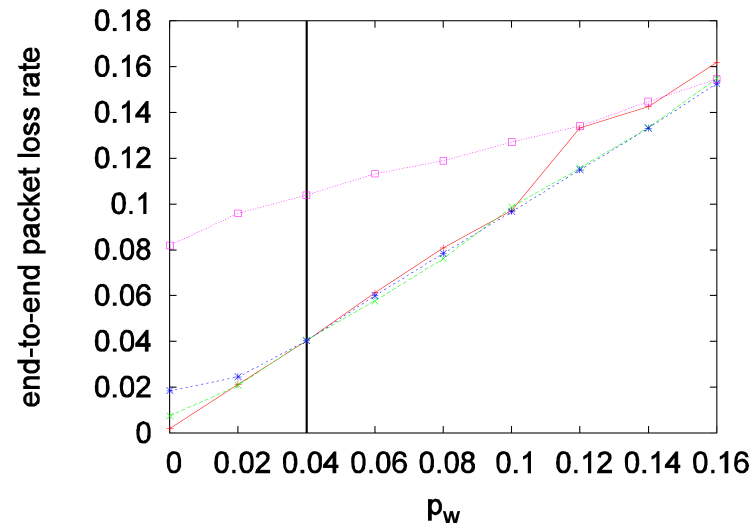
Optimal Number of Connections Exists for Given Settings



- B_w = 1Mbps
- Propagation delay: rtt_{min}=168 ms
- S=1000 bytes
- p_w varies from 0.0 - 0.16
- NS-2 simulation

- n=32



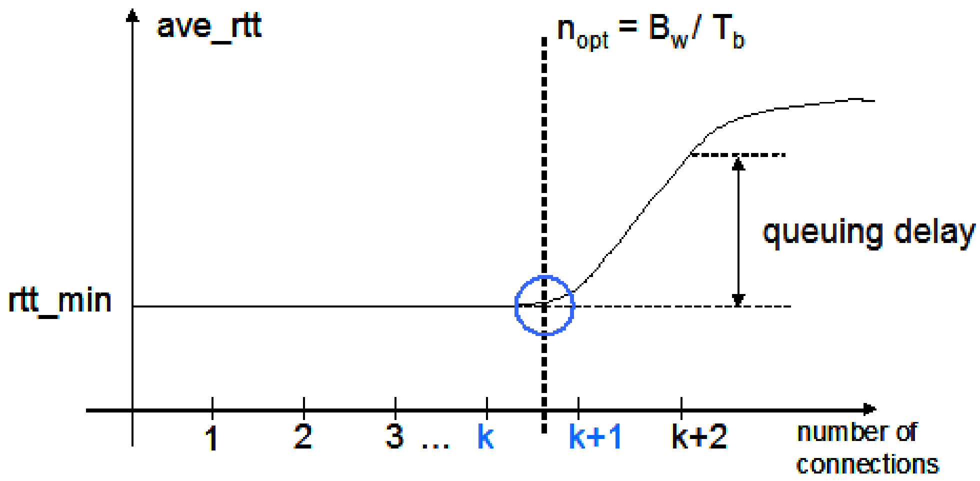


Experimental Evidence

- 1xRTT CDMA data network
- 8 runs, 30 minutes each

number of conn.'s	**throughput (kbps)**	**rtt (ms)**	**pkt loss rate**
one	57	1357	0.018
two	48.2+45.6=94	2951	0.032
three	33.2+31.9+27.8=93	2863	0.046

How to Implement -



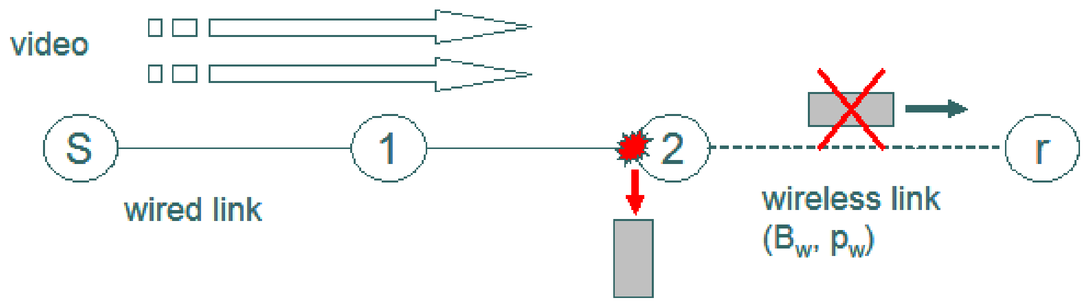
- *ave_rtt* – measured average rtt
- *rtt_min* – propagation delay
- *ave_rtt – rtt_min* – queuing delay

- Inversely Increase and Additively Decrease (IIAD) on number of connections:

$$n = \begin{cases} n - \beta, & \text{if } ave\_rtt - rtt\_min > \gamma\ rtt\_min; \\ n + \alpha/n, & \text{otherwise.} \end{cases}$$

- Empirically choose $\alpha=\beta=1$, and $\gamma=0.25$

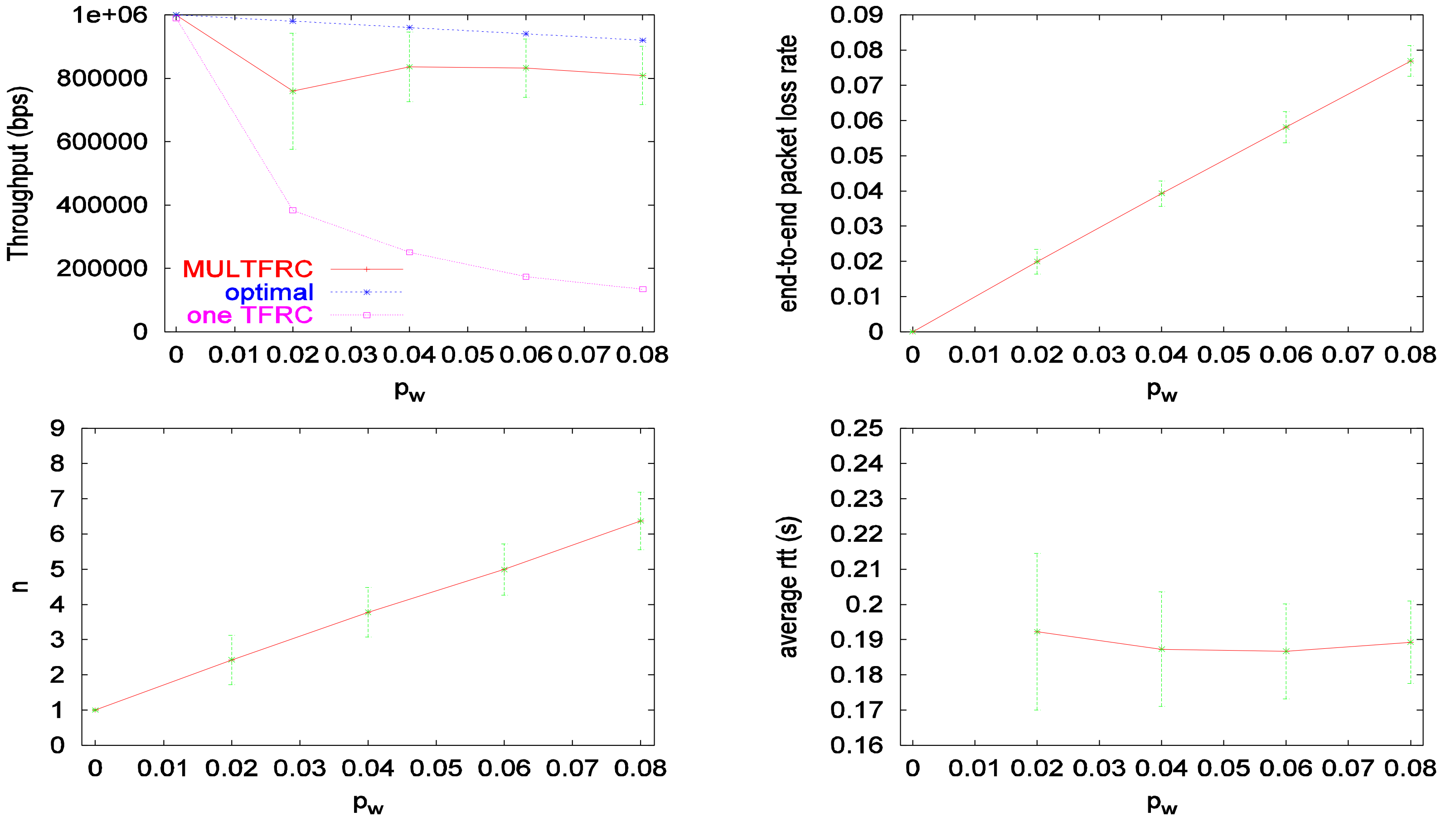
NS-2 Simulation Settings



- p_w varies from 0.00 - 0.08 in an increment of 0.02
- wireless link is simulated using a wired link + exponential error model
- packet size S=1000 bytes
- measure throughput every 10 seconds, end-to-end packet loss rate every 30 seconds, average rtt every 100 packets

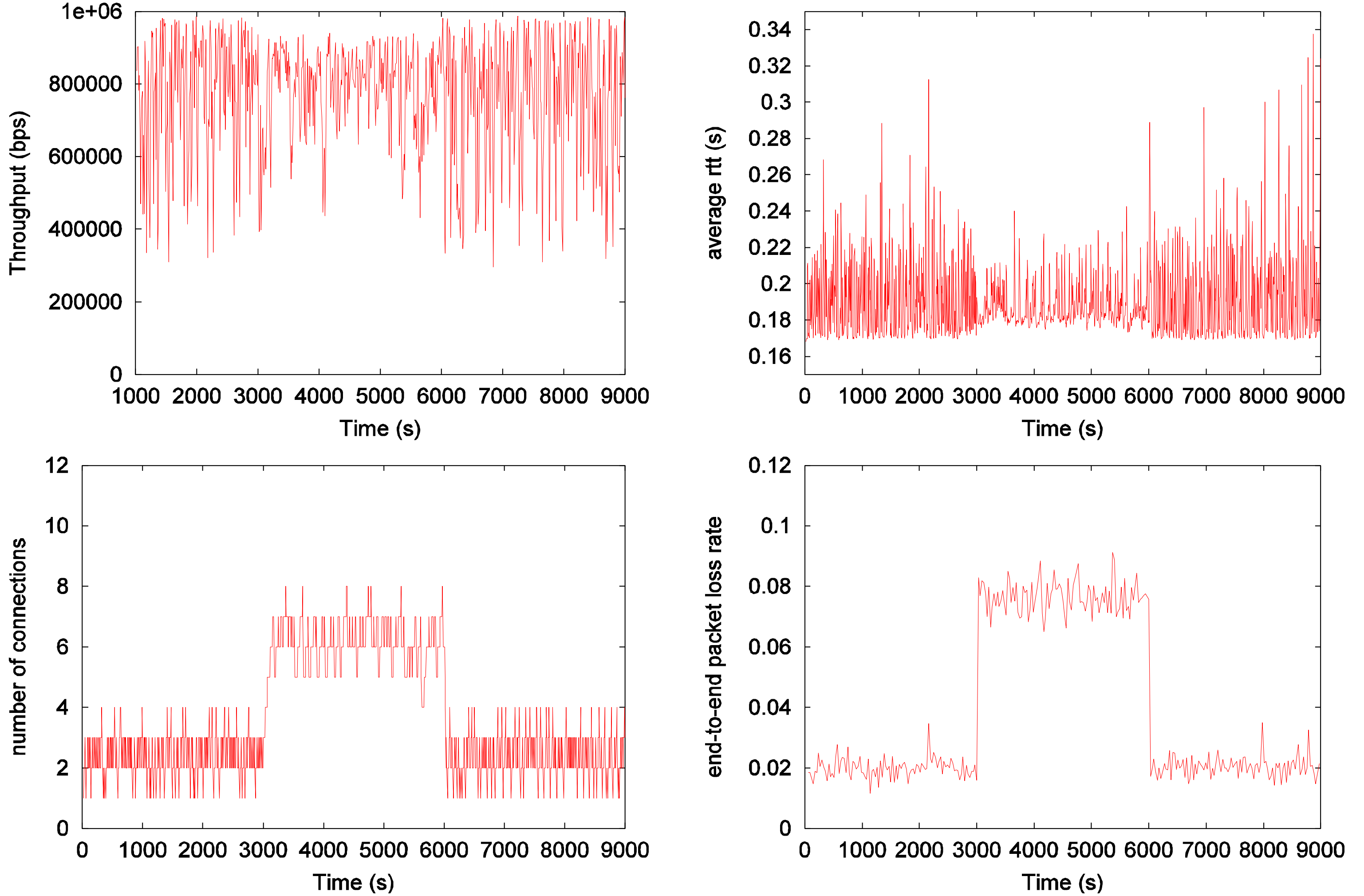
MULTFRC: Performance Characterization

- $B_w = 1$ Mbps, rtt_{min}=168 ms



Adaptivity to Channel Condition

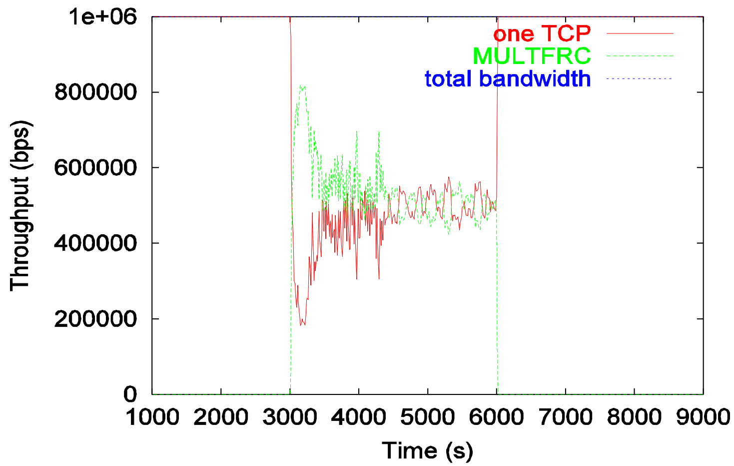
- $B_w = 1$ Mbps, rtt_{min}=168 ms, p_w: 0.02 ! 0.08 ! 0.02

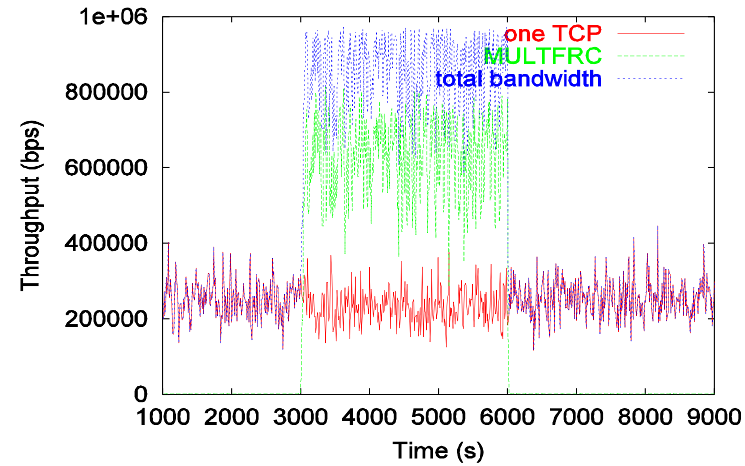


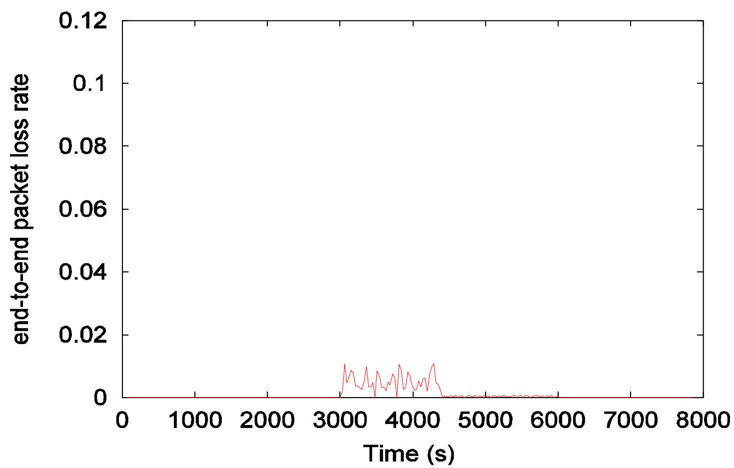
MULTFRC Does not Starve TCP

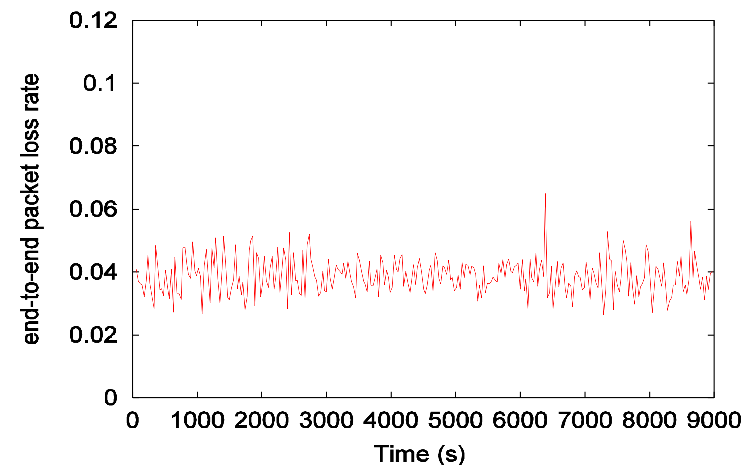
- B_w = 1 Mbps. TCP: 0-9000s; MULTFRC: 3000-6000s

$p_w=0$ | $p_w=0.04$



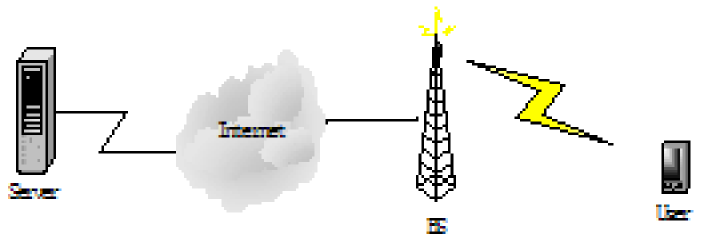






MULTFRC: Works in Practice

- A PC in EECS domain UC Berkeley
- A laptop connected via 1xRTT CDMA network
- Average over 8 runs, each lasts for 30 minutes



scheme	throughput (kbps)	rtt (ms)	packet loss rate	ave. # of conn.
one TFRC	54	1624	0.031	N/A
MULTFRC	86	2512	0.045	1.8

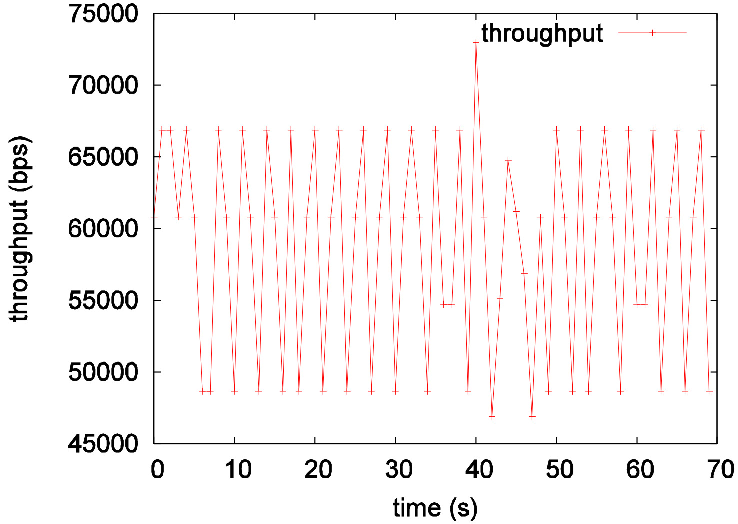
MULTFRC details – for one run

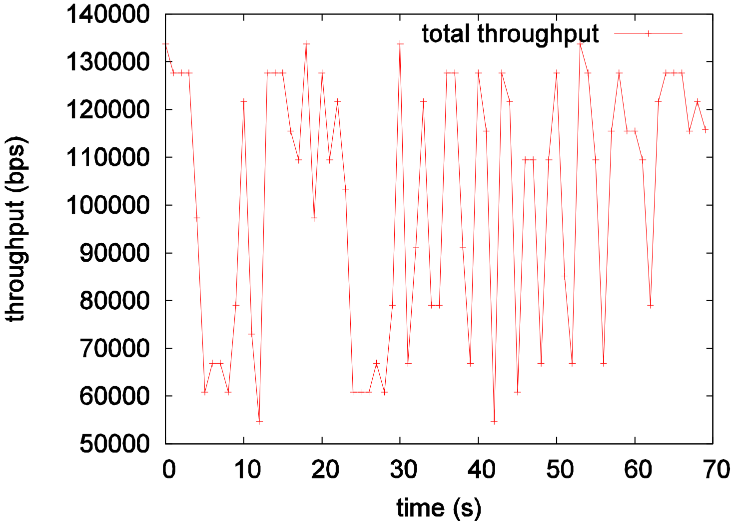
- Average number of connections opened: 1.91

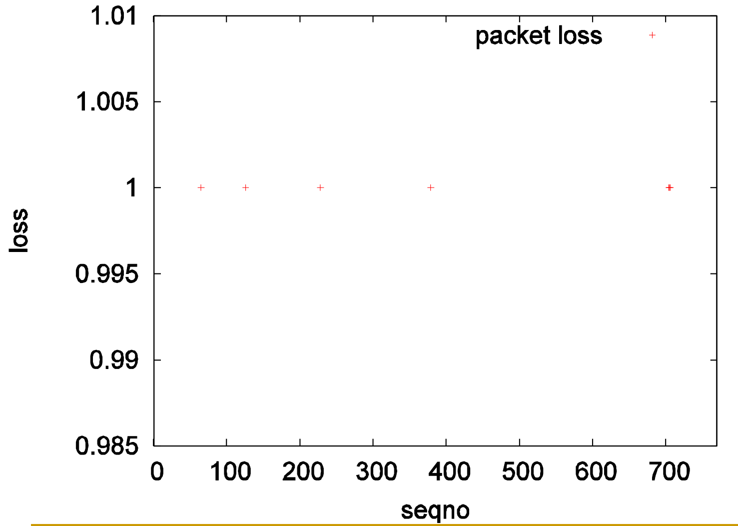
# of connections opened	% of time over 30min	Packet loss rate associated	Error burst length: average	Error burst length: standard deviation	Error burst length: maximum
One	24.6	0.015	2.86	3.43	7
Two	60.1	0.047	2.41	3.63	10
Three	15.4	0.083	3.25	9.93	11

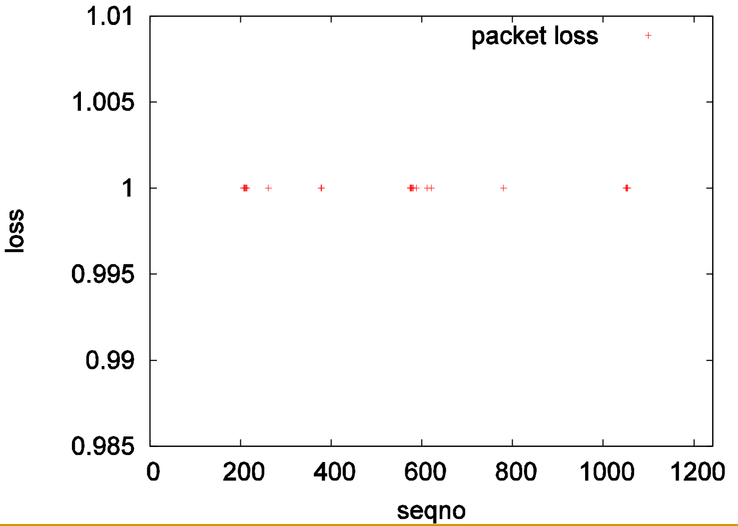
Traces – Throughput and Loss; 70 secs

- One TFRC
- MULTFRC







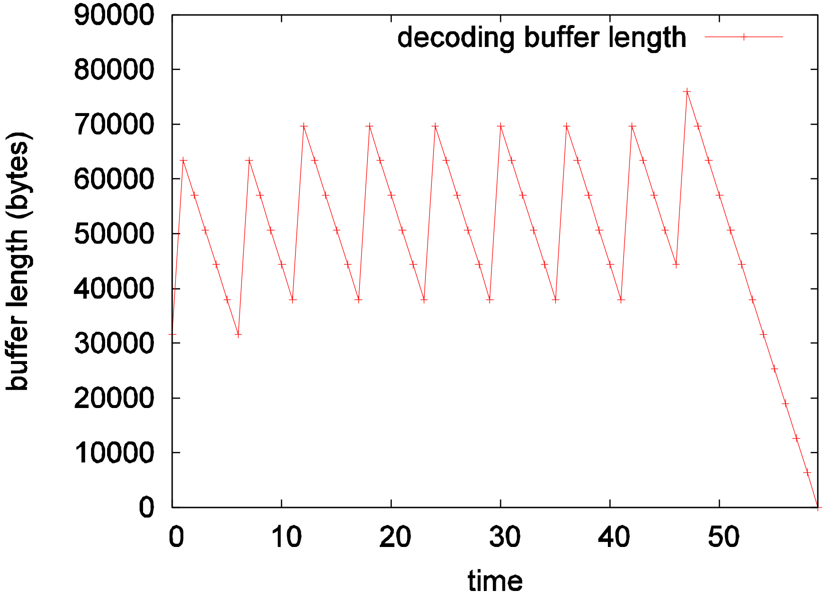


MULTFRC in the Context of Video

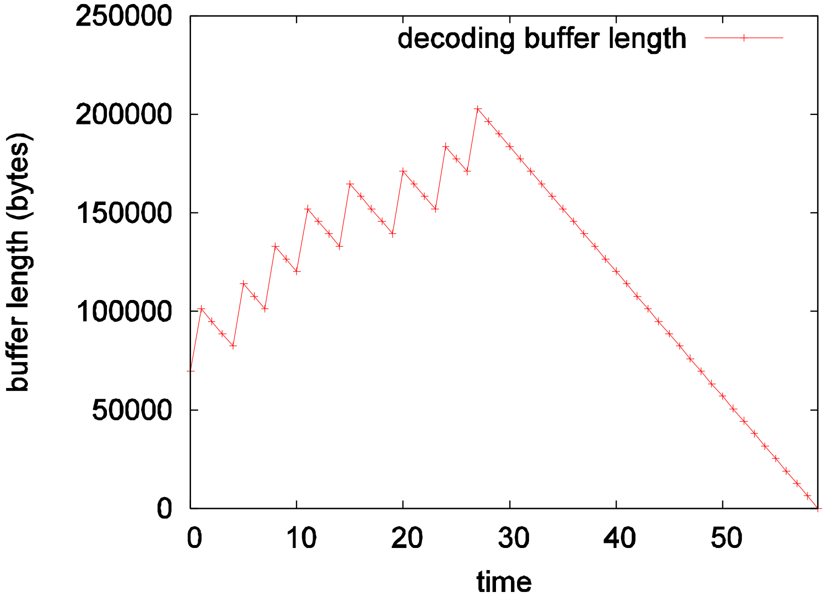
- Sender side:
  - Encode 300 frames news.cif using MPEG-4 encoder
    - Frame rate: 10fps
    - One I frame per 15 frames
    - Apply rate control at rate 50kbps ~ 110kbps
    - Encoded bit streams are packetized with packet size 760 bytes
  - Protect the bit streams with different levels of FEC:
    - RS(61,50) for MULTFRC
    - RS(56,50) for one TFRC
- Channel
  - Simulated using packet receiving and loss traces from actual experiments using MULTFRC and one TFRC
- Receiver side:
  - RS and MPEG-4 decoding
  - 10 second pre-buffering
  - 10 fps palyback
  - Compare the buffer occupancies of MULTFRC scheme and one TFRC scheme

Buffer occupancy – 50kbps case

- One TFRC

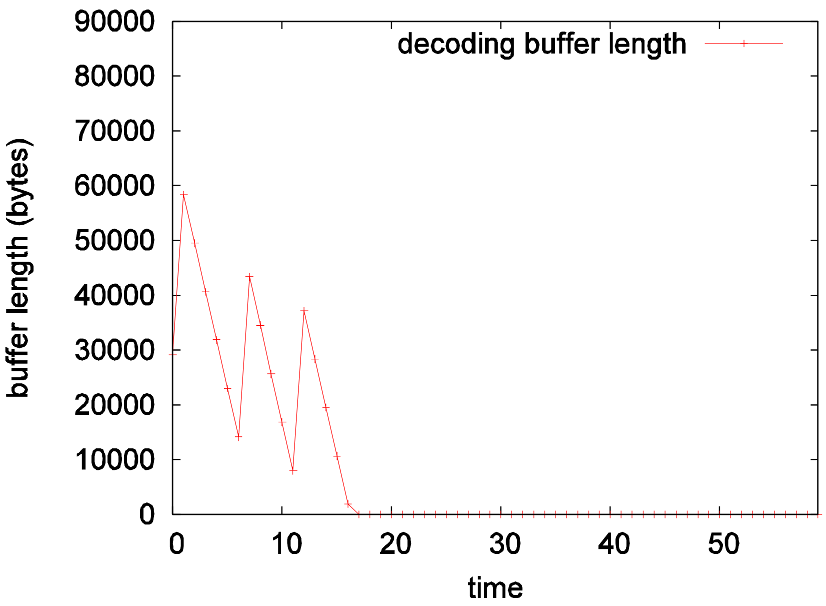


- MULTFRC

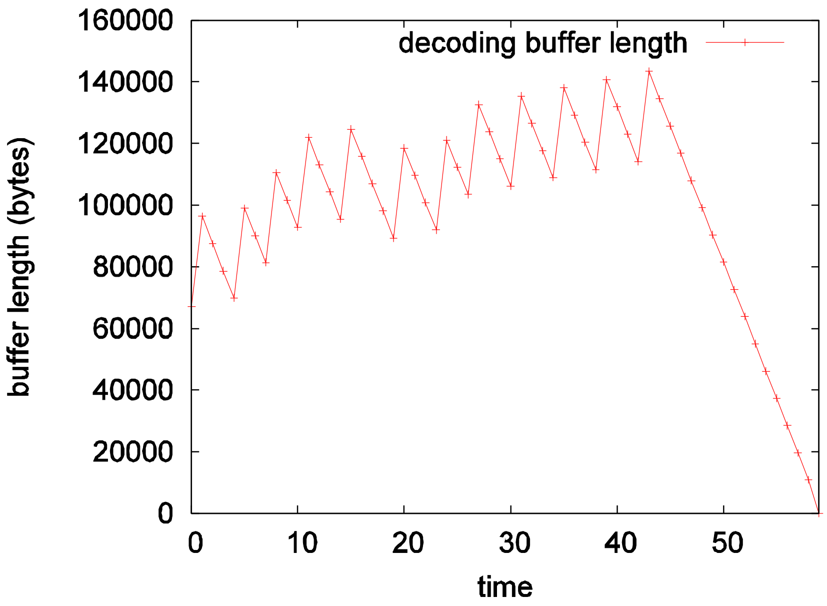


Buffer occupancy – 70kbps case

- One TFRC

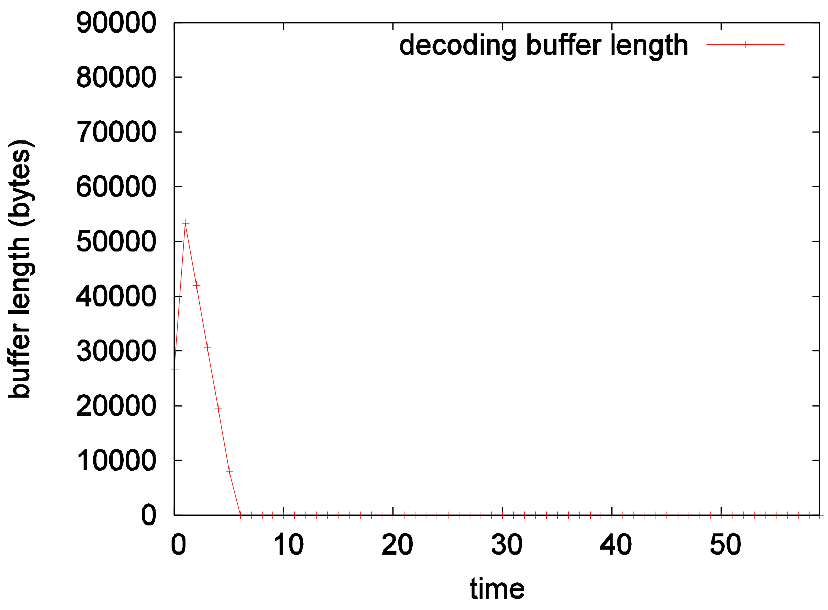


- MULTFRC

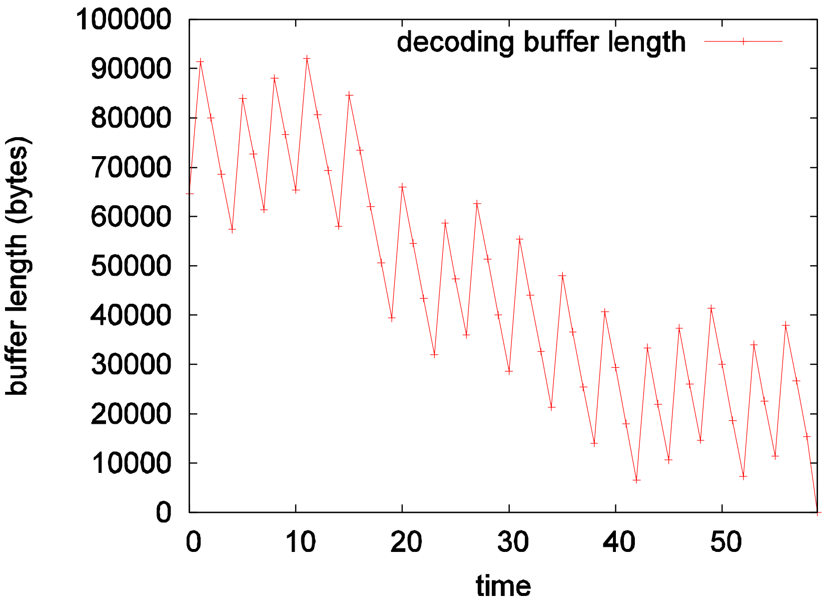


Buffer occupancy – 90kbps case

- One TFRC



- MULTFRC



Conclusions:

- MULTFRC can support higher bit rate video transmission than One TFRC even though it needs a stronger FEC.
- This is primarily due to the higher receiving throughput achieved by MULTFRC

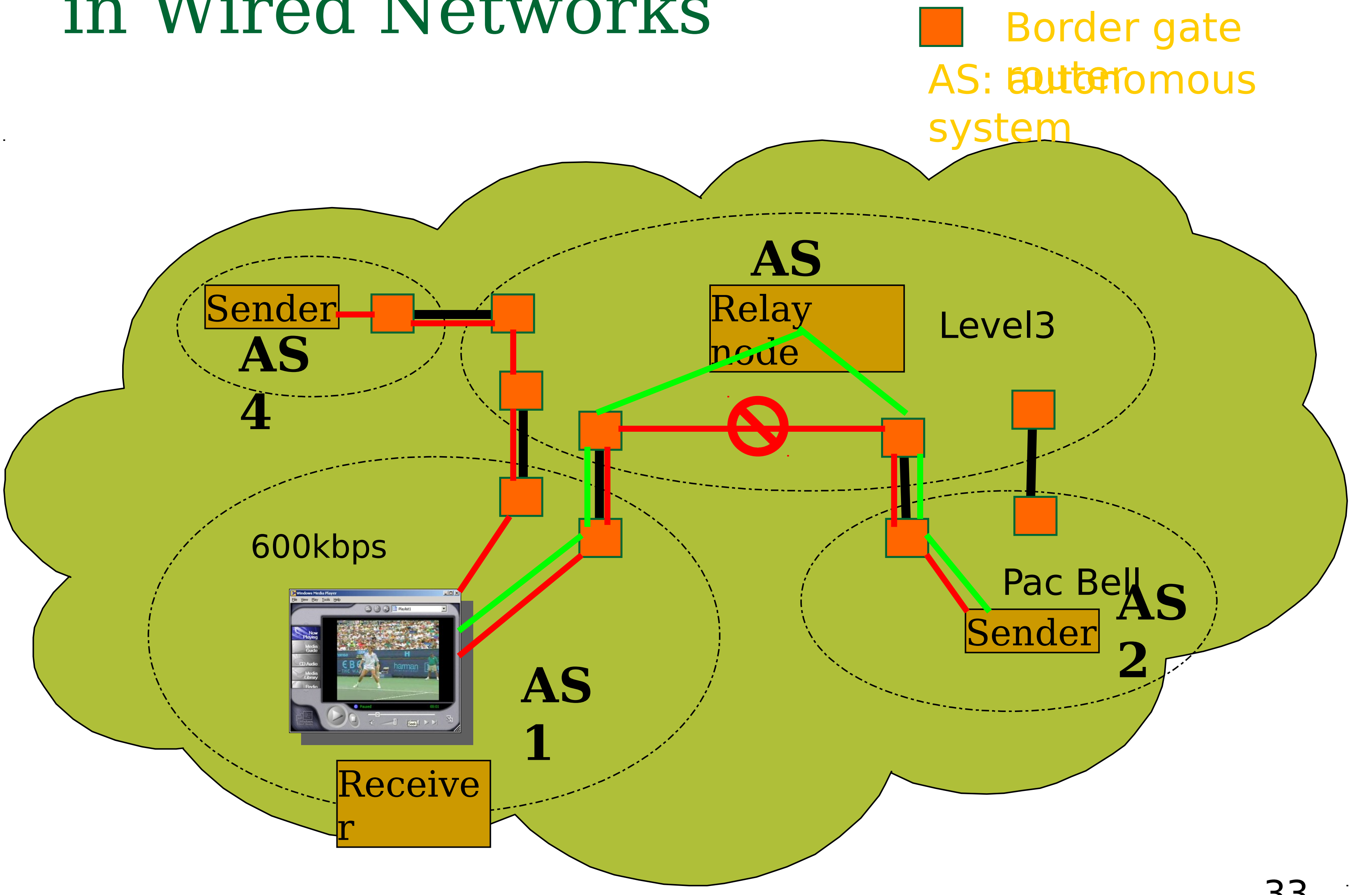
Futre work: Globally Converge to Stable Point?

- Q.: Is it possible to achieve highest throughput and lowest packet loss rate, using an end-to-end solution?
- A: Multiple TFRC connections
- Also work for DATA (TCP) over wireless
- Limitation: need to detect route change to update the propagation delay estimate, i.e. rtt_{min}
- Future work: what if widely deployed?
  - both number of connections and sending rate of each connection are dynamically varied
  - will network converge to stable and optimal point?

How to exploit path diversity in multimedia communication overwireless networks?

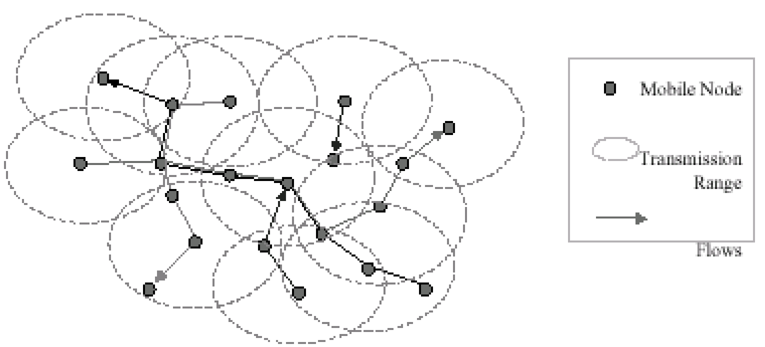
- In centralized wireless networks, this is equivalent to adding more base stations as relays
- How about adhoc networks?
  - Unicast:
  - Multicast:
- Can we combine this with multiple description coding or FEC?

Distributed/Multipath Streaming in Wired Networks



How about path diversity in wireless ad hoc networks?

- What is an wireless ad hoc network?
  - A collection of wireless mobile nodes
  - Infrastructure-less dynamic wireless network
  - Each mobile node acts both as a host and as a router
- Challenges for video streaming over ad hoc networks
  - Highly dynamic topology causes frequent route breakage.
  - Multiple wireless links have high random packet loss.

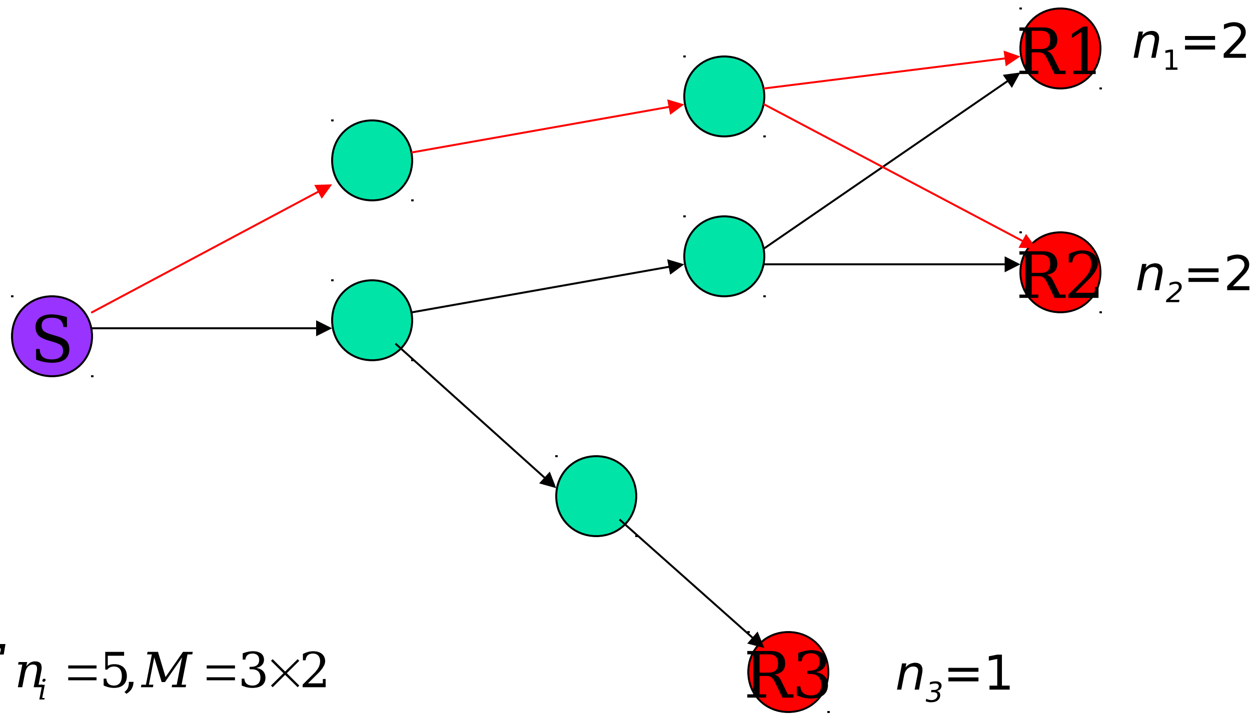


Multiple Tree Multicast Video Streaming

- Multicast streaming over wireless ad hoc networks is important
  - Applications: group video conferencing and video distribution
  - Saves bandwidth compared to multiple unicast sessions
- Goal: exploit tree diversity to provide robustness
  - Would more trees decrease connectivity?.
  - Need to define tree connectivity first.

Tree Connectivity Level

Two trees case



$$N=\sum_{i=1}^{m} n_i = 5, M = 3\times 2$$

$$tree\ connectivity = P = \frac{N}{M} = \frac{5}{6}$$

Tree Connectivity is a value from 0 to 1.

Definition of Tree Connectivity Level

- Tree connectivity level is defined as $p = \frac{E[N]}{M}$
  - M = # of receivers x # of trees
  - $N = \sum_{i=1}^{m} n_i$
  - n_i = # of trees connected to receiver i
  - Expectation is over all random topologies with one random sender and m random receivers
  - The higher tree connectivity, the better

Problem to Explore

- Multiple disjoint trees schemes reduce connectivity level compared to single tree schemes, but increase robustness.
- Do multiple disjoint trees schemes have to increase node density significantly to keep a good connectivity level?
  - If so, tree diversity technique is not effective/practical

.

Related Works

- Gupta and Kumar 1998
  - To have asymptotic connectivity, node density goes to infinity if the number of nodes goes to infinity.

- Percolation Theory (Dousse *et. al.* 2002, Meester *et. al.* 1996)
  - If node density is larger than a certain value, there exists one unique unbounded connected super-cluster almost surely.

Problem Formulation and Analysis Assumption

- Problem Formulation: Given tree connectivity level *P*, what is the relation between D_1 and D_2?
  - D1 : minimal node density to achieve P for a single tree scheme
  - D2 : minimal node density to achieve P for a double disjoint tree scheme

- Analysis Assumption
  - Dense network
    - there exists one unbounded connected super-cluster *H*.
  - Infinite number of total nodes
  - The ratio of the number of receivers to the number of total nodes is very small.

Analysis Result (I)

- Tree connectivity level for the single tree case :

$$P_1 \approx \theta_1^2$$

θ_1 : the fraction of nodes belonging to the supercluster *H*.

- There exists at least one disjoint double tree scheme whose tree connectivity level *P* can be represented as:

$$P_2 \approx \frac{\theta_2^2}{2} + \frac{P^2(R \in H')}{2}$$

θ_2 : the fraction of nodes belonging to the supercluster *H*

H' : the connected supercluster after removing all the middle nodes of the first tree

$$P(R \in H') \approx 1 - \pi D_2 r^2 \exp(-\pi D_2 r^2) - \exp(-\pi D_2 r^2)$$

Analysis Result (II)

- Main Result: Given a tree connectivity level *P*, there exists at least one disjoint double tree:

$$D_2 - \frac{\ln(\pi D_2 r^2 + 2)}{\pi r^2} \leq D_1 \leq D_2$$

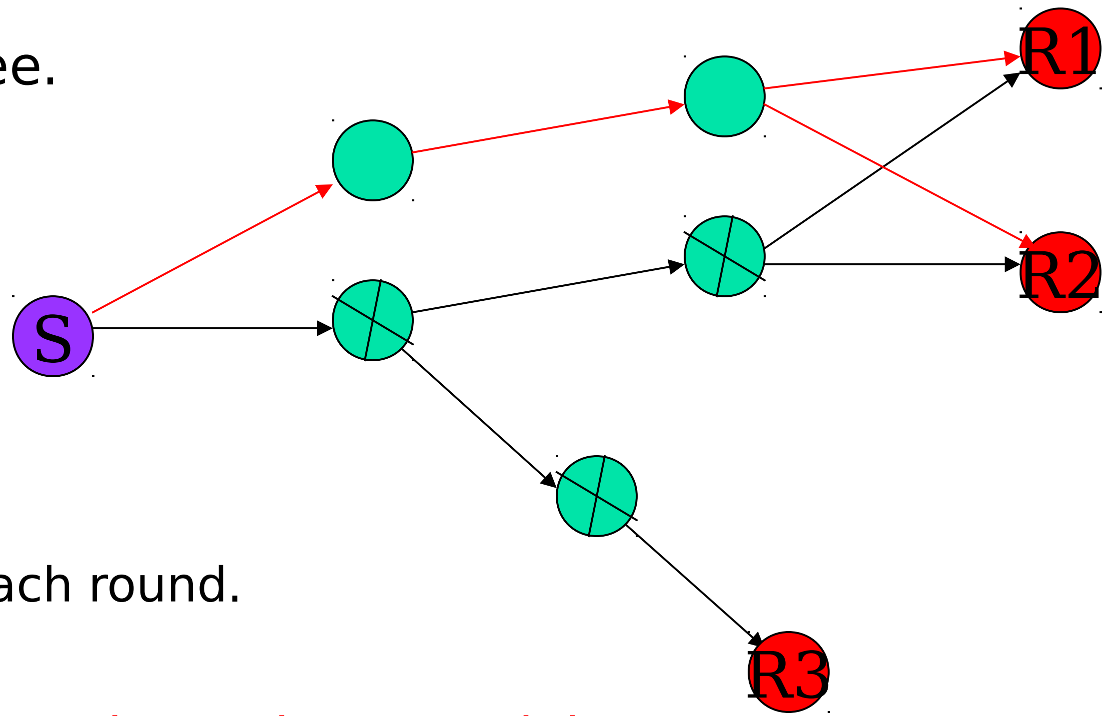
  - D_1 : required node density to achieve *P* for a single tree scheme
  - D_2 : required node density to achieve *P* for the double disjoint tree scheme
  - r : radio range
- Corollary: The required density of one disjoint double tree scheme is not significantly larger than that of a single tree scheme.

Serial Disjoint Double Tree Construction

Build the first tree.

Disable the middle nodes of the first tree.

Build the second tree.



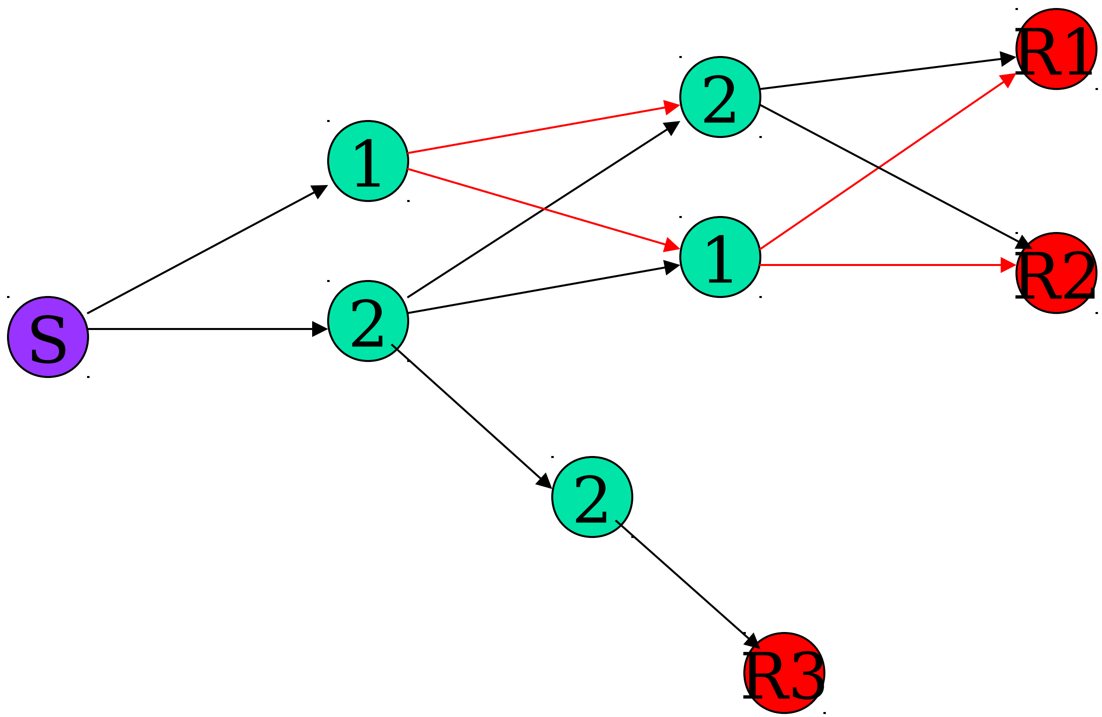
Broadcast twice in each round.

- Advantage: disjointed, good connectivity
- Disadvantage: routing overhead, delay

Parallel Double Tree Construction

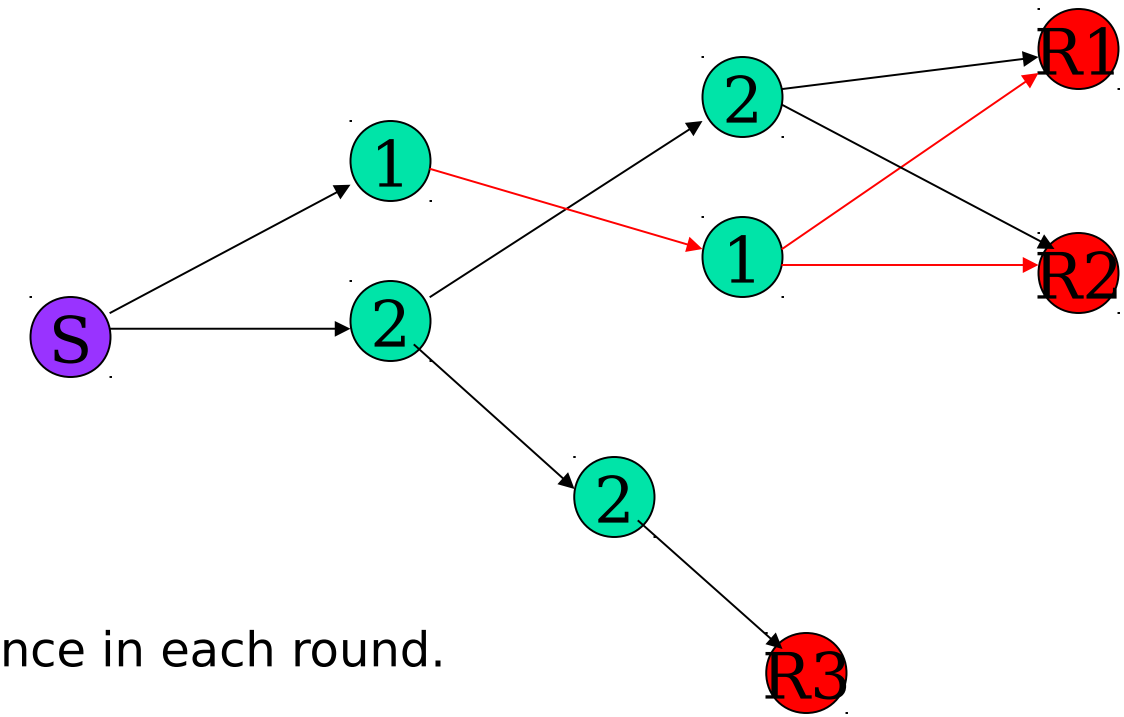
Each node randomly picks a group ID.

Each node only forwards the Routing message from a node in the same group, or from the sender



Parallel Double Tree Construction

The two trees look like this.



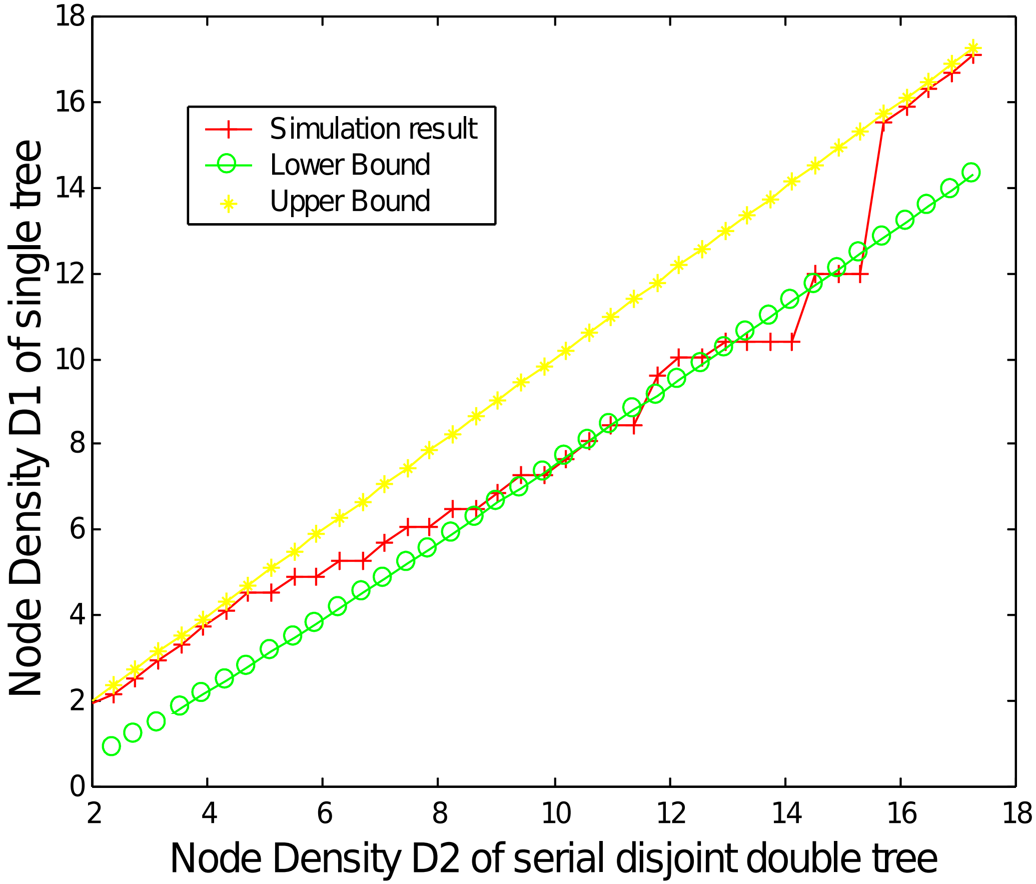
Broadcast only once in each round.

- Advantage: low overhead, low delay
- Disadvantage: low connectivity

Improve Connectivity of Parallel Double Tree Construction at the Expense of Disjointness/Robustness

- Introduce general nodes as bridges between high density areas.
  - General node: node density of its neighborhood is *smaller* than a threshold value.
  - Forward routing messages from nodes of both groups
- Make distribution of nodes in each local area more even.

Simulation 1: Relation between D_2 and D_1



D_1: Density of Single Tree

D_2: Density of Double Tree

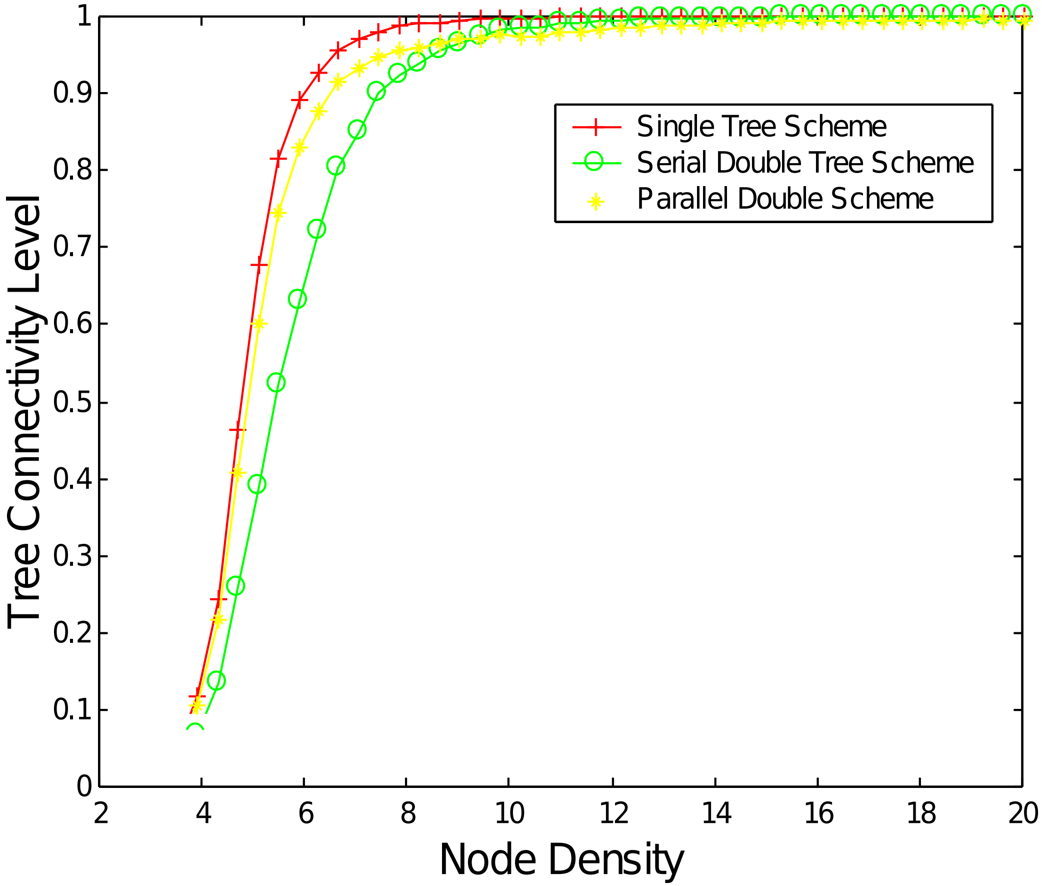
- Upper Bound: $D_1 = D_2$
- Lower Bound:

$$D_1 = D_2 - \frac{\ln(\pi D_2 r^2 + 2)}{\pi r^2}$$

$$D_2 - \frac{\ln(\pi D_2 r^2 + 2)}{\pi r^2} \leq D_1 \leq D_2$$

Observation: simulation points lie in between upper and lower bour

Simulation 2: Comparison of tree connectivity of single tree scheme, serial double tree scheme, and parallel tree



- 1000 nodes
- 5 receivers
- 2-D poisson process
- 5000 experiments
- *r*: 25 pixels

Observation: parallel scheme also has good connectivity

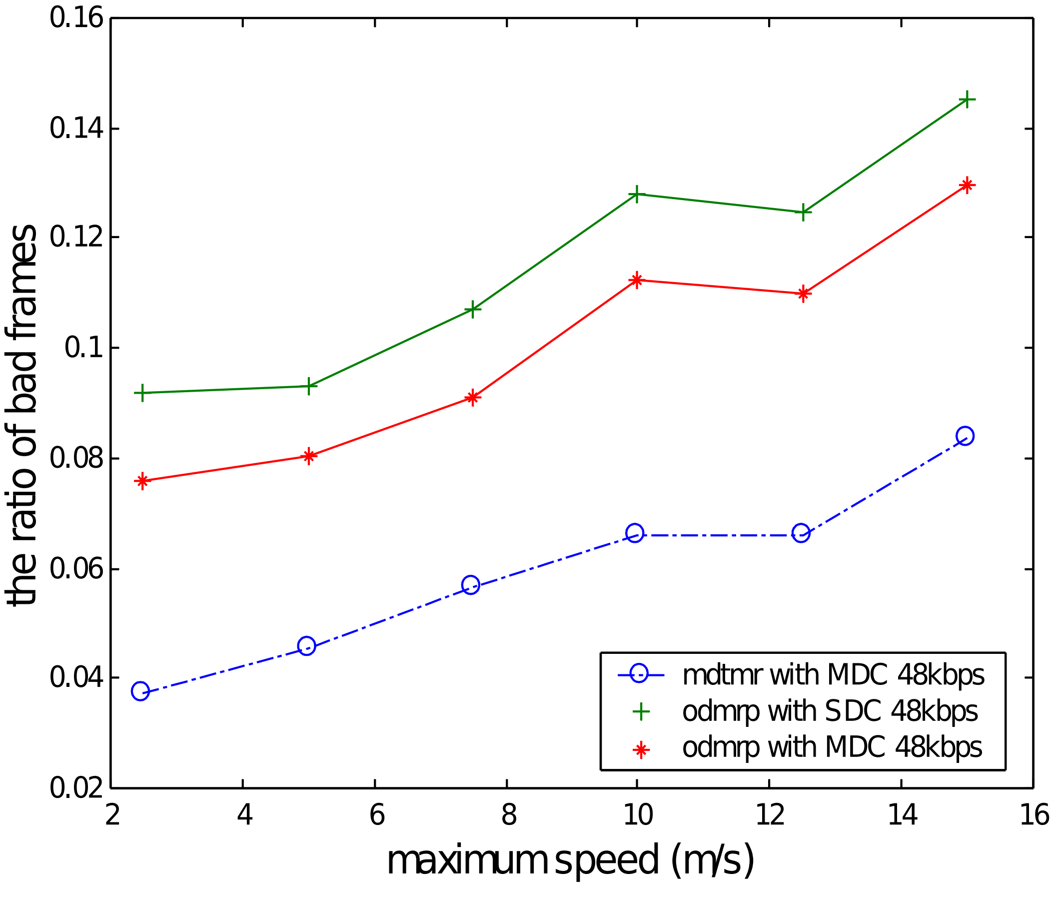
Simulation 3: Performance evaluation of video multicast streaming.

- NS simulation Scenario:
  - 65 nodes in 1350 meters by 1200 meters area
  - One sender, eight receivers, bit rate is 48 kbps, playback rate is 8 fps
  - The playback deadline of each packet is 150 ms
  - Simulations are run for 900 seconds.
  - Results are averaged over 30 simulations.
  - nodes continuously move with the maximum speed from 2.5 m/s to 15 m/s.
- Schemes:
  - Serial MDTMR (Multiple Disjoint Trees Multicast Routing) with MDC.
  - ODMRP (On-demand Multicast Routing, single tree) with SDC.
  - ODMRP with MDC.

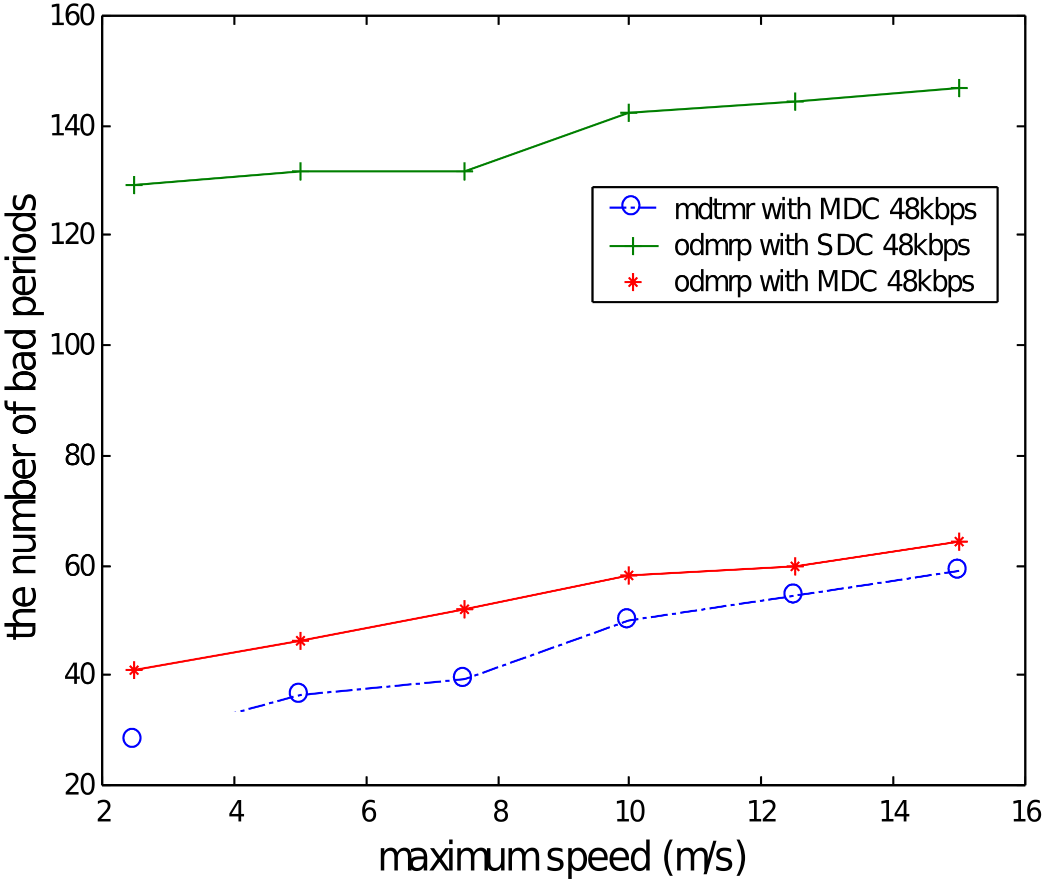
Performance evaluation (II)

- Terminology and metrics:
  - bad frame: a frame with none of its two packets received
  - bad period: a period of contiguous bad frames
  - The ratio of bad frames: the ratio of the number of bad frames over the number of all frames
  - The number of bad periods
  - Routing overhead: the number of control packets per frame
  - Forwarding efficiency: the number of forwarded packets per received packets

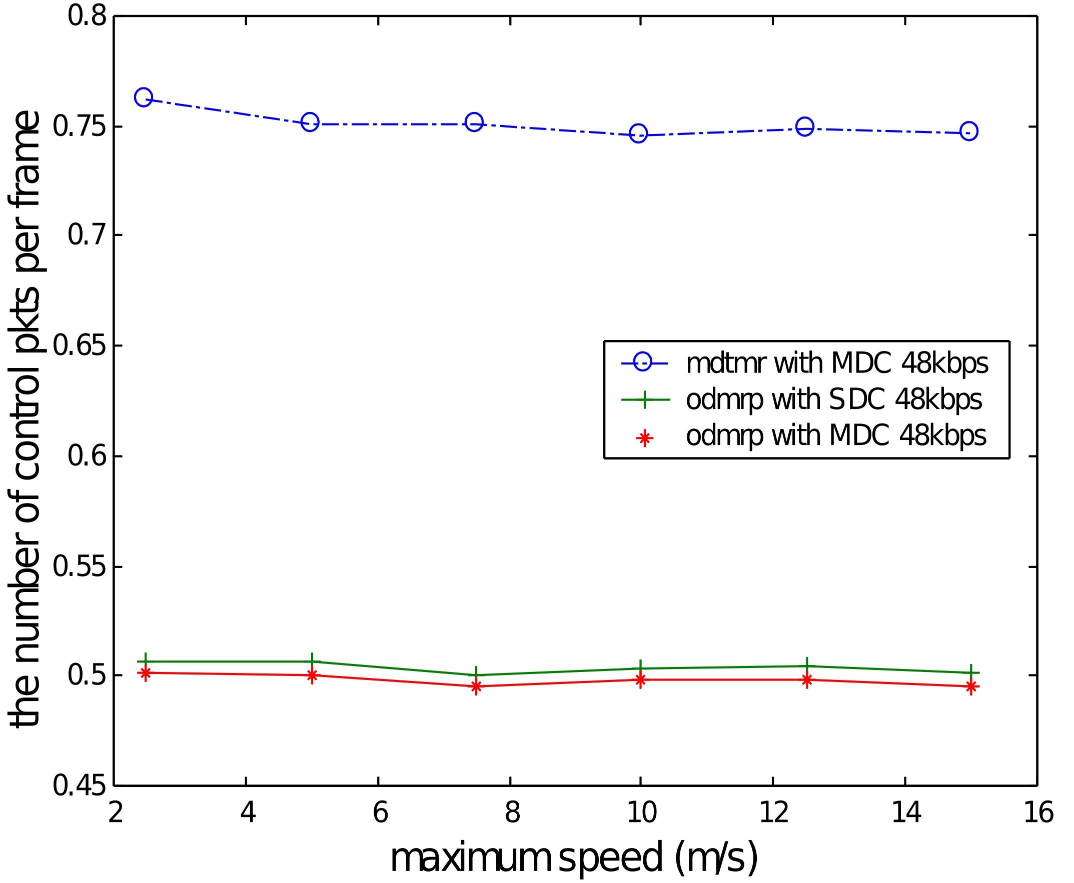
The ratio of bad frames of Serial MDTMR with MDC is much smaller than that of other two schemes.



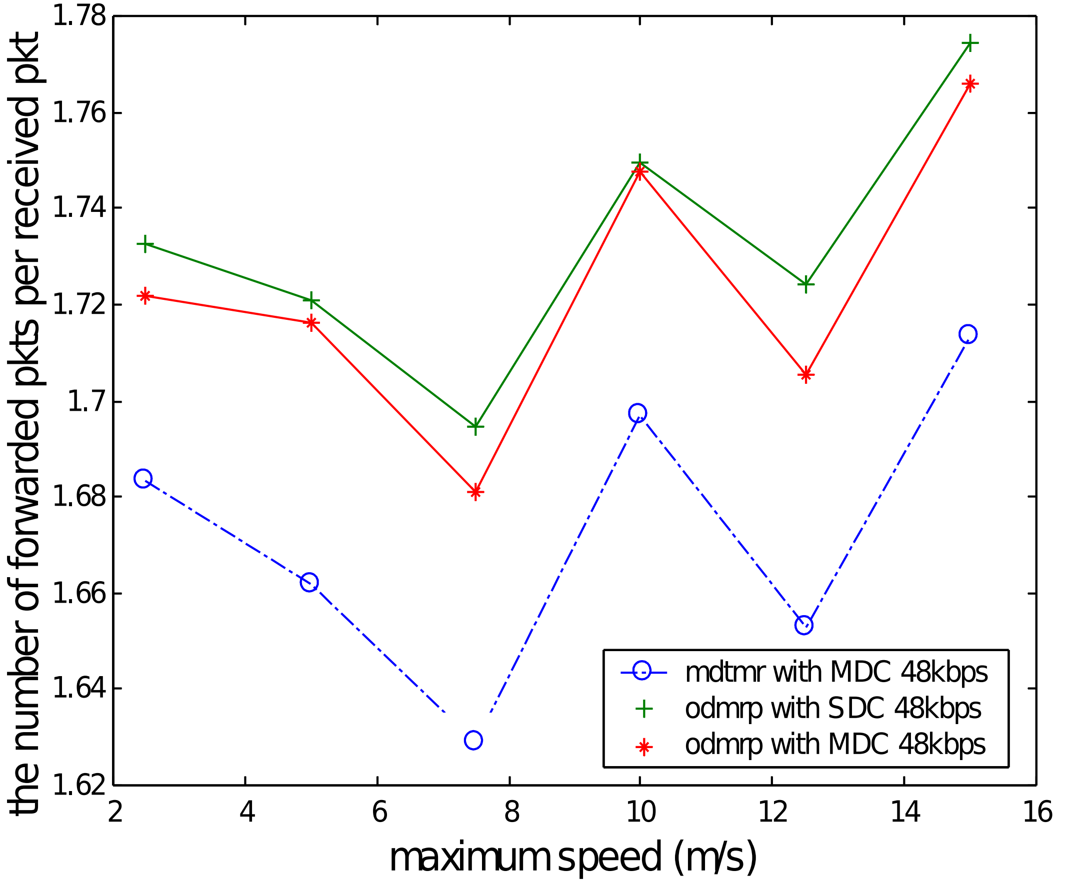
The number of bad periods of Serial MDTMR with MDC is smaller than that of other two schemes.



The number of control packets of Serial MDTMR with MDC is larger than that of other two schemes. The size of each control packe



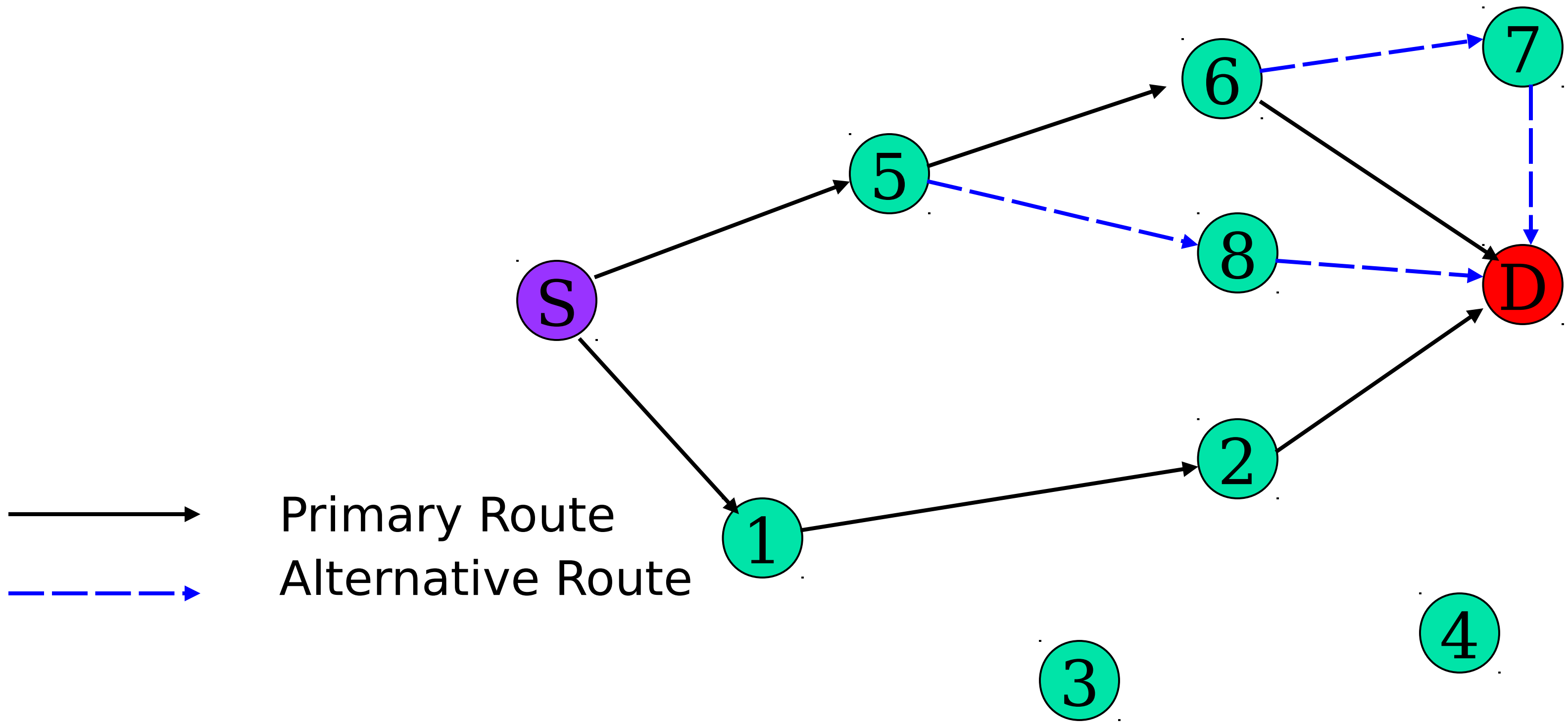
The forwarding efficiency of three schemes is almost the same, and MDTMR is slightly better than other two.



How about mutlipath unicast streaming in wireless adhoc networks?

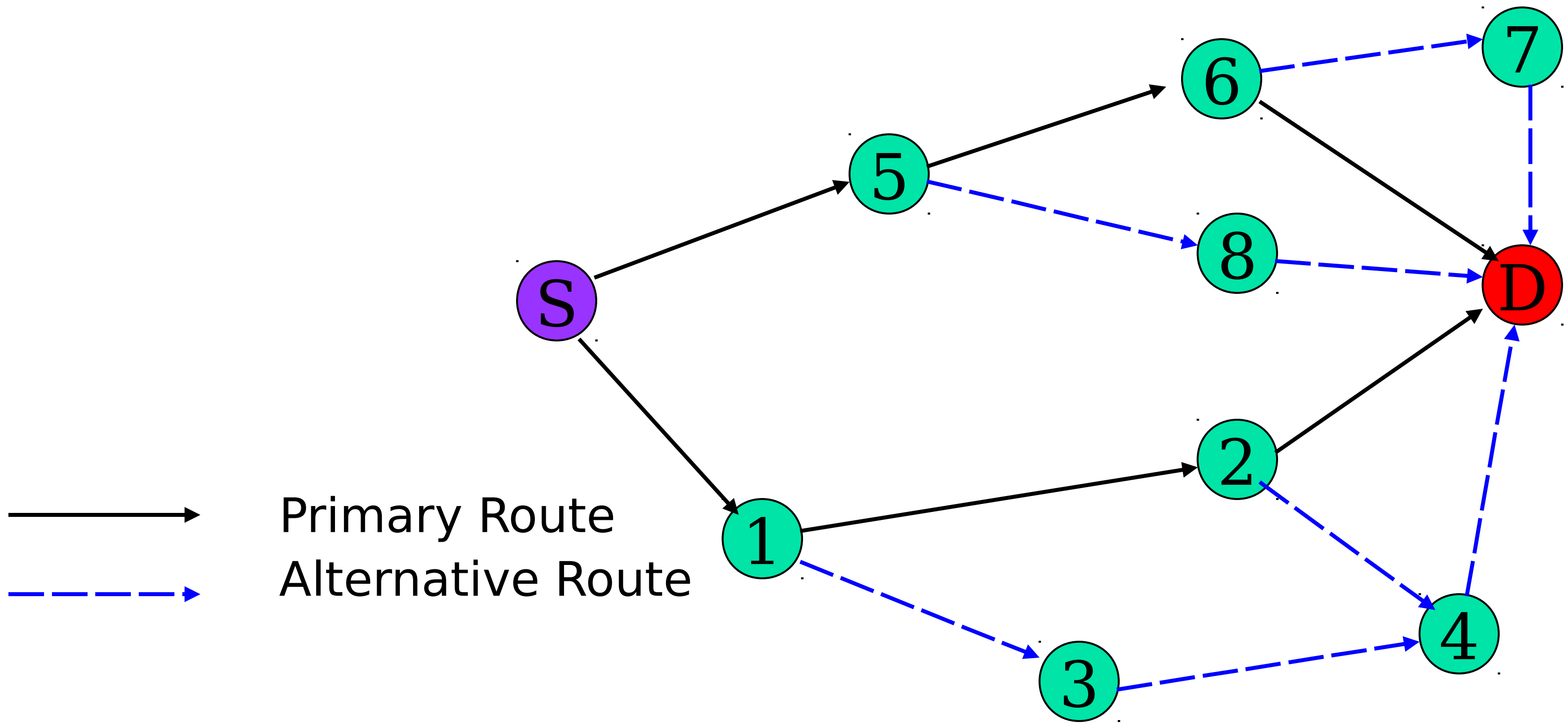
Robust Multipath Source Routing Protocol (RMPSR)

- Builds multiple nearly disjoint route sets.
- A route set: One Primary Route and Several Alternative Routes.
- Nearly disjoint: the ratio of # of shared nodes to # of the nodes of the shorter route is smaller than a threshold.



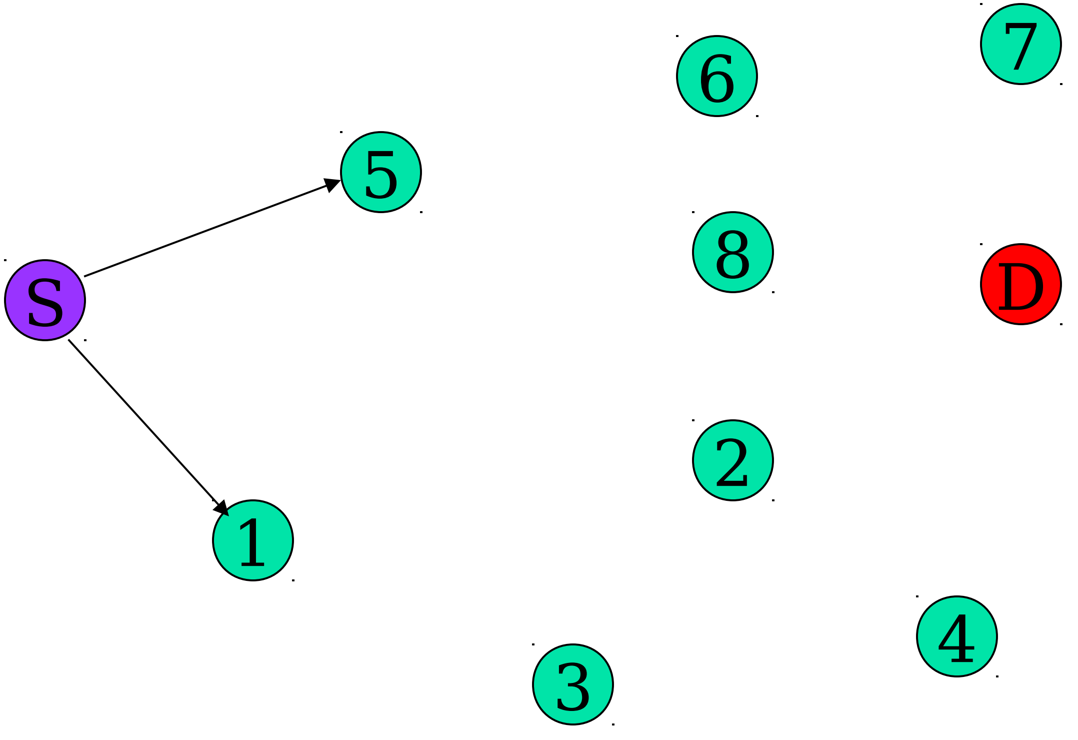
Robust Multipath Source Routing Protocol (RMPSR)

- Nearly Disjoint route sets: Primary routes are nearly disjoint.
- An alternative route and the corresponding subroute of the primary route are nearly disjoint.



RMPSR (Route Sets Building)

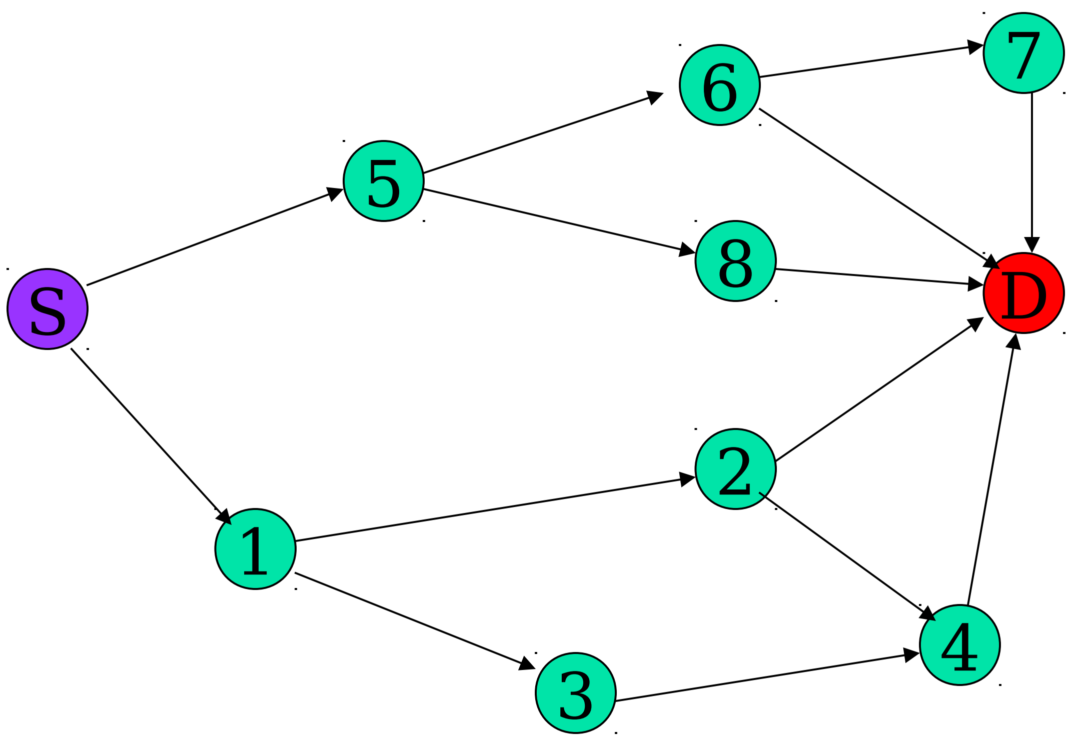
The sender initiates the Route Discovery Process:



RMPSR (Route Sets Building)

A middle node forwards a Route Query packet iff:

- non-duplicate
- OR the path in the new Route Query packet is disjoint with previous



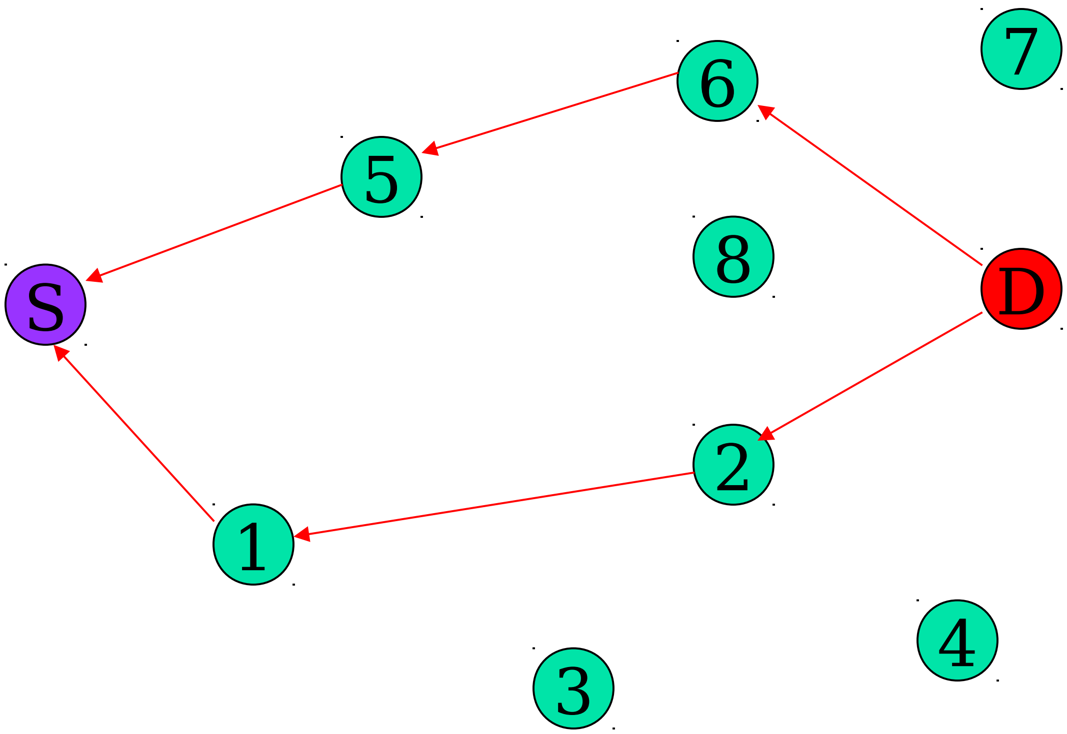
Information received in the Destination Node

- S->5->6->D
- S->5->8->D
- S->5->6->7->D
- S->1->2->D
- S->1->3->4->D

...

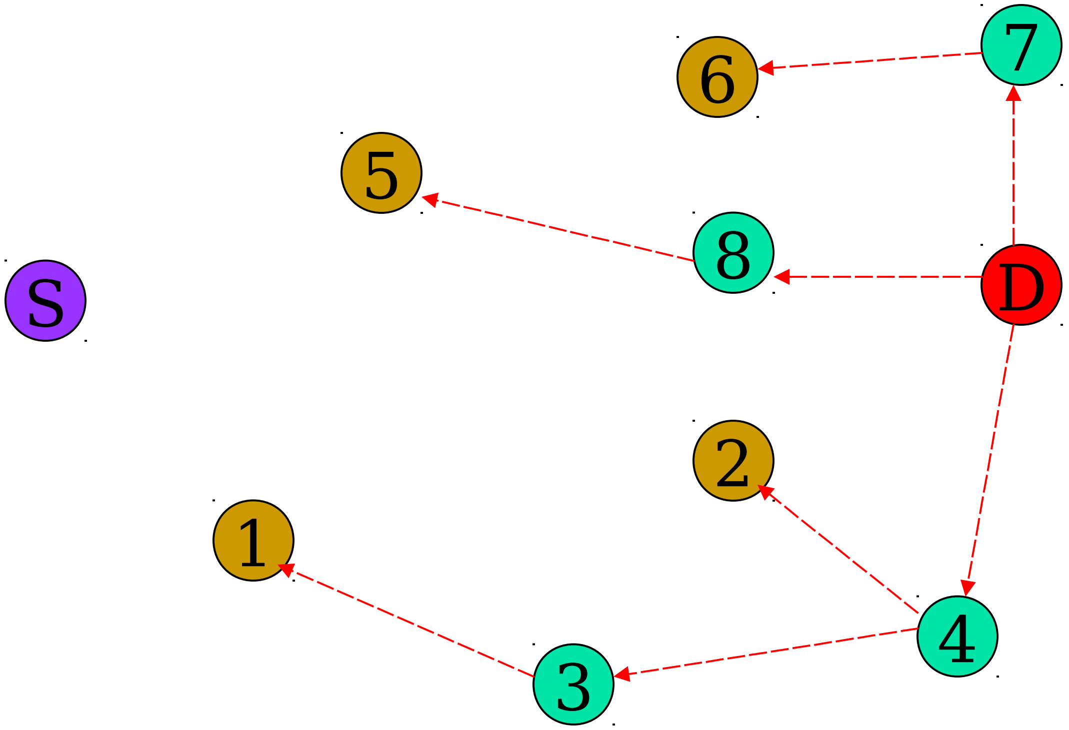
RMPSR (Route Sets Building)

The destination node computes lowest latency, nearly disjoint prima
routes and sends those to the Sender



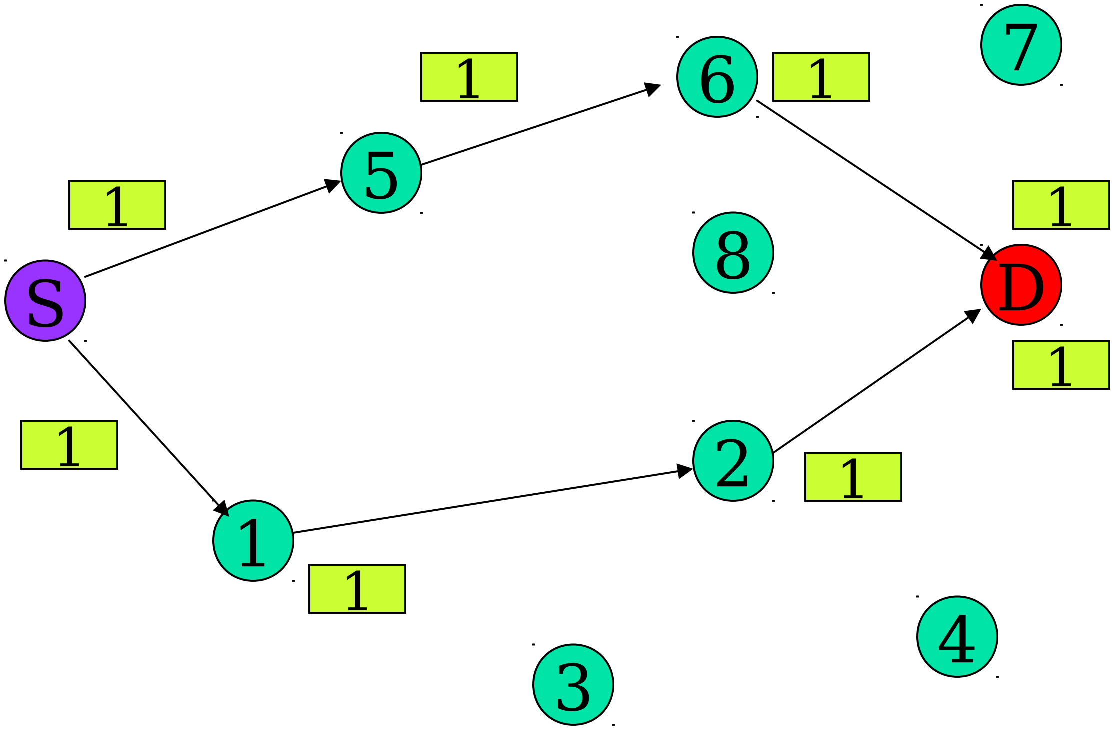
RMPSR (Route Sets Building)

The destination node computes and returns alternative routes of each route set to the corresponding middle node.



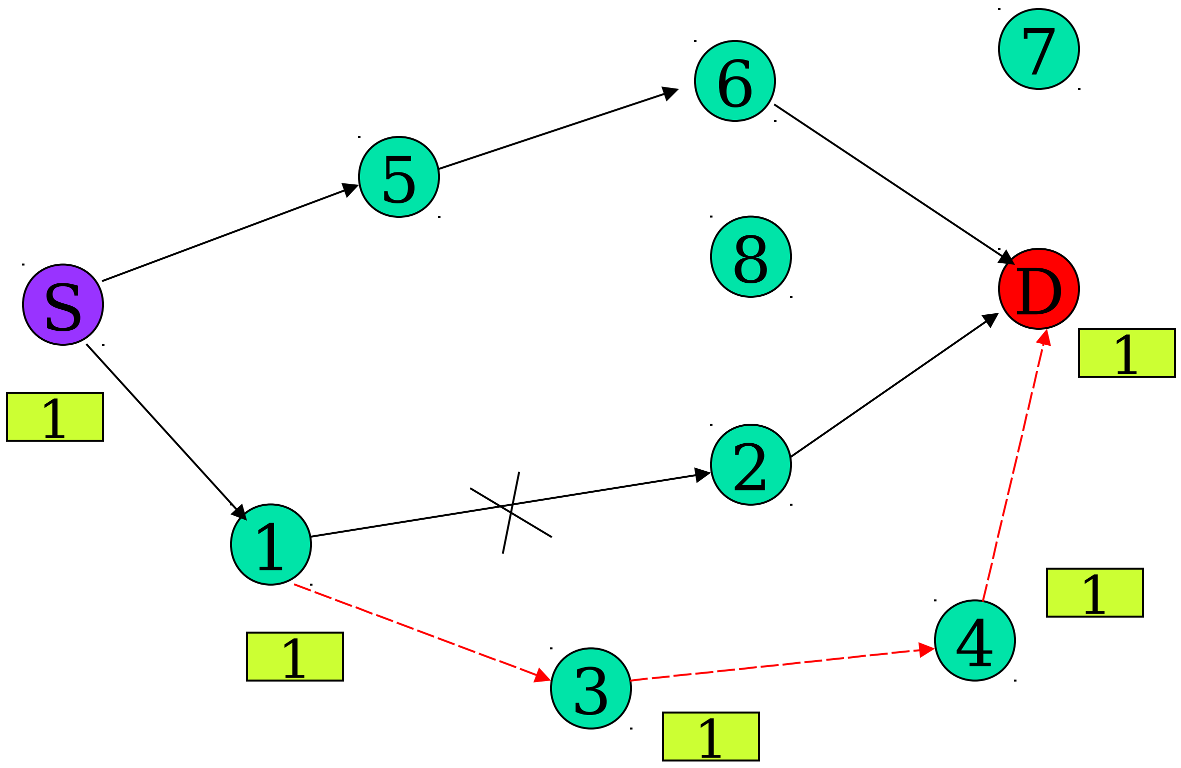
RMPSR (Packets Forwarding)

Transmit MDC video packets over multiple paths simultaneously.



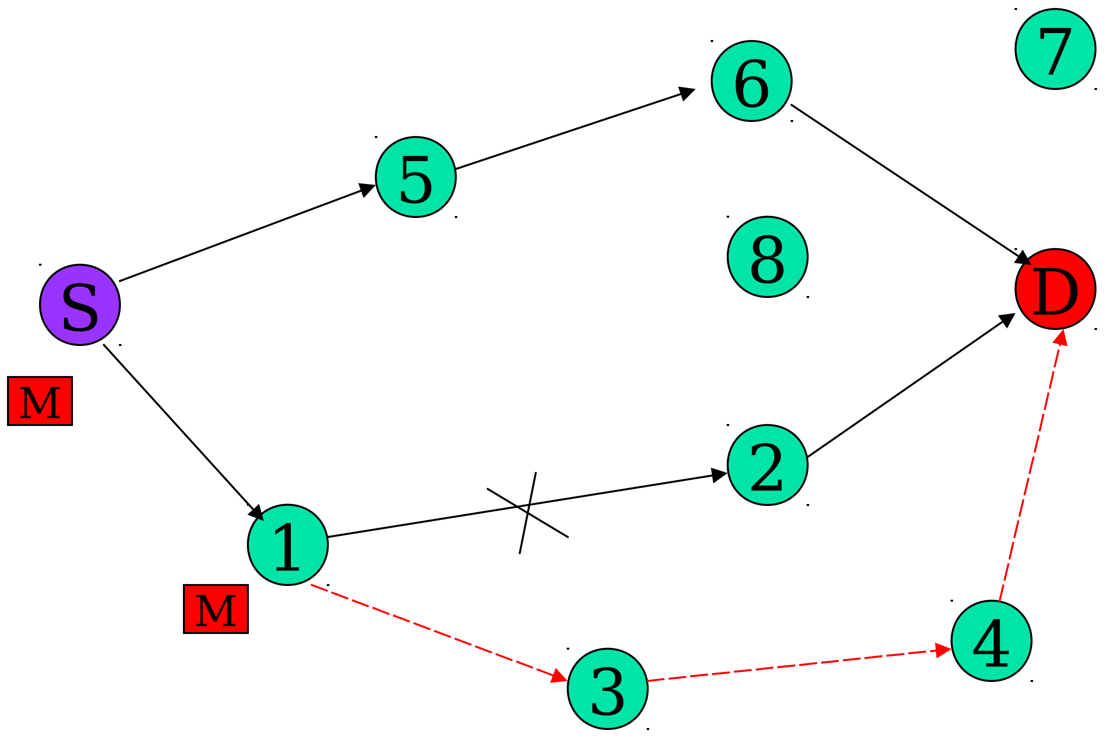
RMPSR (Route Sets Maintenance)

If one primary route is broken, alternative routes in the same route will salvage mid-way video packets.



RMPSR (Route Sets Maintenance)

In the meantime, the node corresponding to the broken link sends a Route ERRor packet to the sender.



RMPSR (Highlights)

- RMPSR builds multiple nearly disjoint route sets.
- Alternative routes are used to salvage mid-way packets, when the transmitting primary route is broken.
- RMPSR triggers new route request process before the connectivity is entirely lost.
  - Reduce the number of temporary network outages during the transmission.
- To alleviate the impact of routing overhead, RMPSR is only applied to video packets, while DSR is applied to other traffic.

Performance evaluation of interactive video applications.

- NS simulation Scenario:
  - 60 nodes in 1200 meters by 800 meters area
  - one 192 kbps video stream + five 12 kbps cross sessions
  - The playback deadline of each packet is 100 ms
  - Simulations are run for ten hours.
  - nodes continuously move with the maximum speed from 2.5 m/s to 15 m/s.

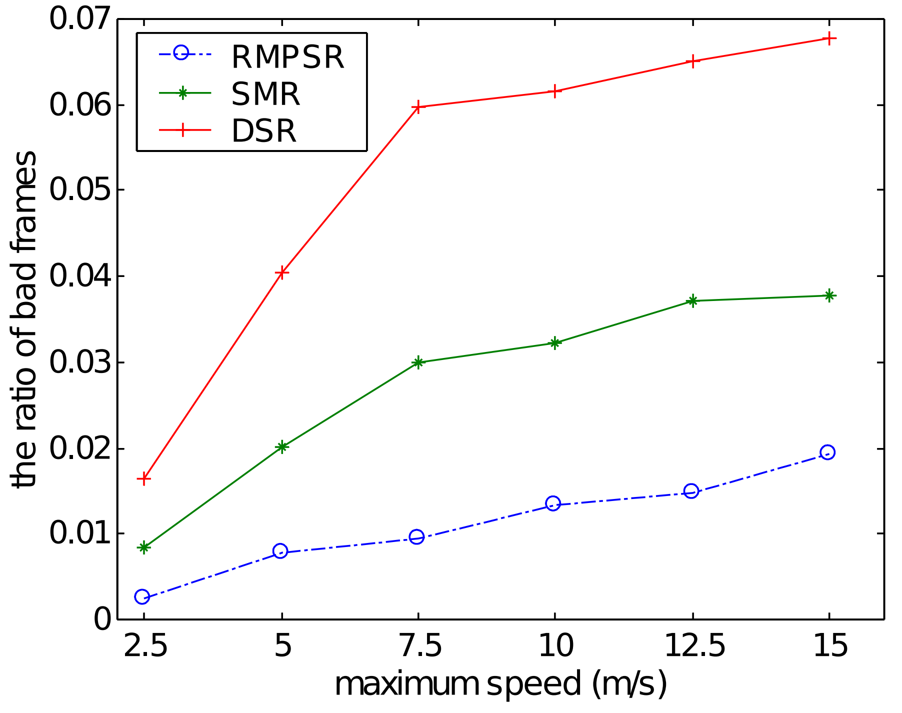
- Terminology and metrics:
  - bad frame: a frame with none of its two packets received
  - bad period: a period of contiguous bad frames
  - The ratio of bad frames: The ratio of the number of bad frames over the number of all frames
  - The number of bad periods

Performance evaluation (II)

- Schemes:
  - DSR with single path video transmission with MDC.
  - SMR with multipath video transmission with MDC.
  - RMPSR with multipath video transmission with MDC.

Performance evaluation (III)

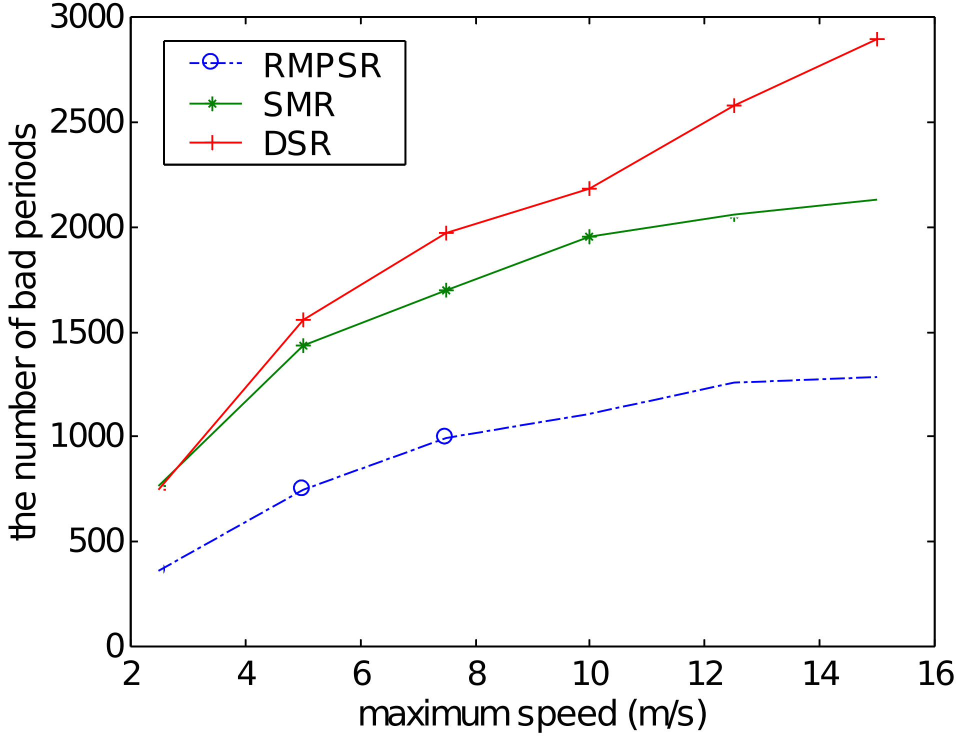
The ratio of bad frames of RMPSR is much smaller than that of other two schemes.



(a) Ratio of bad frames

Performance evaluation (IV)

The number of bad periods of RMPSR is much smaller than that of other two schemes.



(b) Number of bad periods

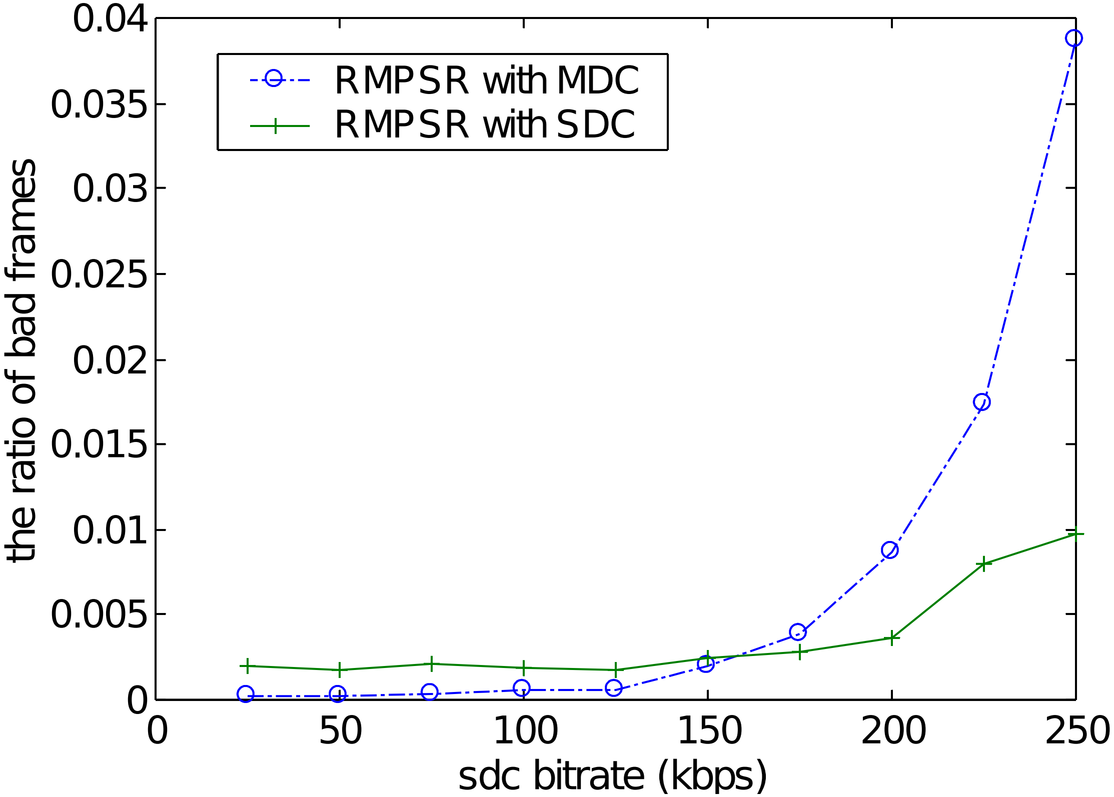
Performance evaluation (V)

- Maximum speed: 12.5 m/s
- the ratio of # of salvaged packets to # of transmitted p
- RMPSR is much larger than other two protocols

Comparison of salvaged packets			
	RMPSR	SMR	DSR
Ratio of salvaged packets	0.0078	0	0.0023

Performance evaluation (MDC vs. SDC)

- Bit rates of MDC are 33% higher
- There exists one threshold value
  - Above: SDC is better
  - Below: MDC is better



Performance evaluation (Video On Demand)

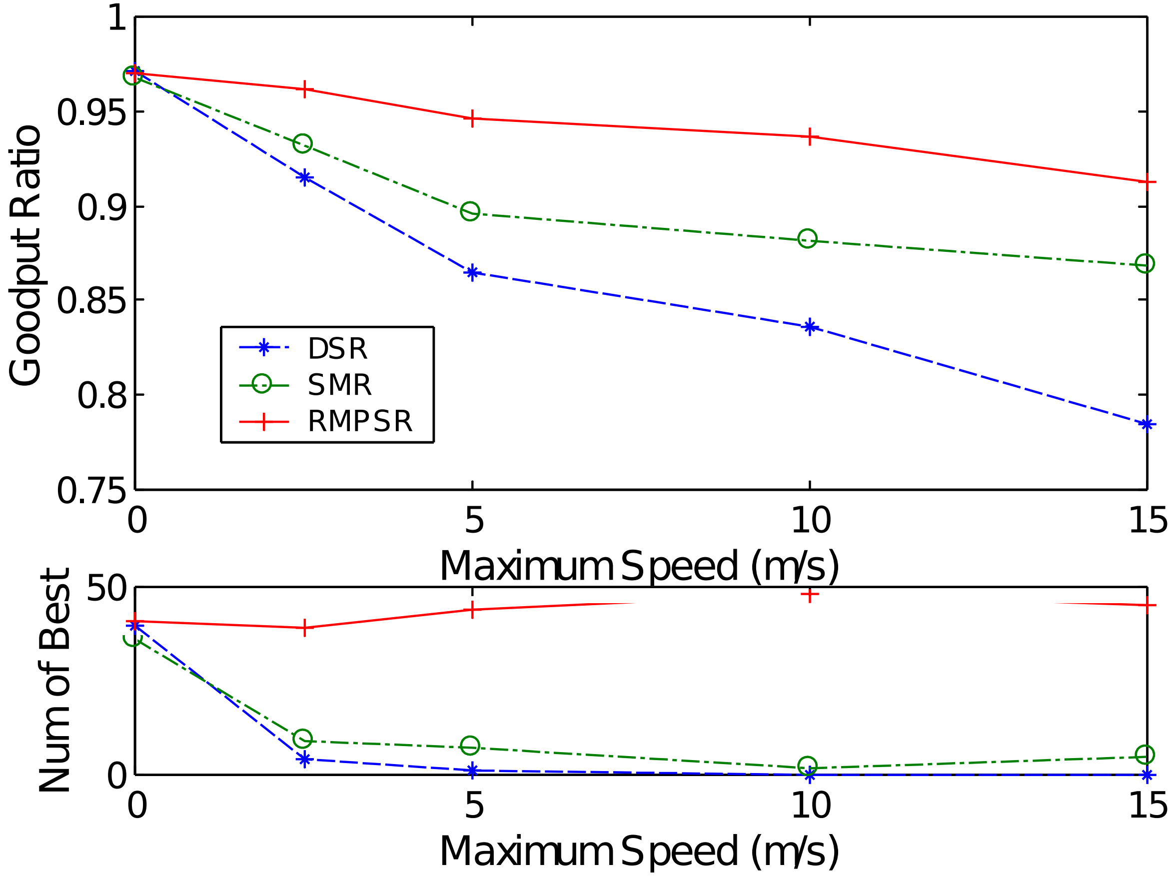
- NS simulation Scenario:
  - 50 nodes in 1200 meters by 800 meters area
  - one 192 kbps video stream + five 12 kbps cross sessions
  - FEC: (100,75) Reed-Solomon erasure code
  - Simulations are run for 600 seconds.
  - 50 Simulations
  - 5 seconds' pre-buffering
  - nodes continuously move with the maximum speed from 2.5 m/s to 15 m/s.

- Terminology and metrics:
  - Goodput ratio: Ratio of # of packets playbacked to # of transmitted packets
  - Number of Rebufferings

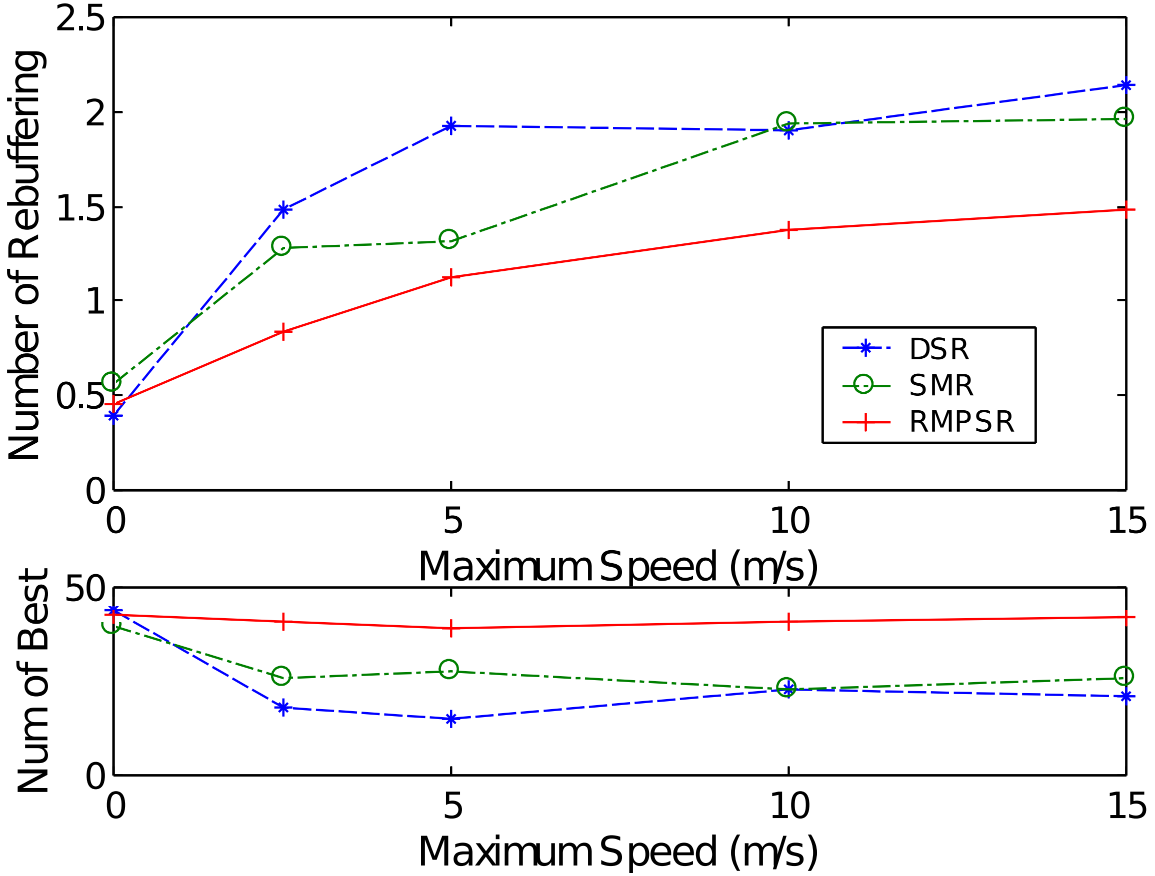
Performance evaluation (II)

- Schemes:
  - DSR with single path video transmission with FEC.
  - SMR with multipath video transmission with FEC.
  - RMPSR with multipath video transmission with FEC.

RMPSR loses much fewer packets than either SMR or DSR prot



RMPSR suffers fewer freezes at the receiver in dynamic scen



Future Work

- Future Work
  - Study how to distribute video streams among disjoint multicast trees.
  - Study the influence of different video coding schemes on multiple trees multicast streaming over wireless ad hoc networks.
  - Build a testbed with multiple laptops, and test the proposed multicast streaming techniques in the testbed.